VALUE OF SATURATION FLOW IN VERMONT

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Introduction

The Highway Capacity Manual (1) defines the saturation flow rate as the flow rate per lane at which vehicles can pass through an intersection. It is the number of queued vehicles per hour that can pass through a signalized intersection if the green signal were available for the full hour and no lost time was experienced. If the saturation flow rate cannot be measured for prevailing geometric, traffic and environmental conditions, a base saturation flow rate is adjusted for the site conditions. The Highway Capacity Manual (HCM) assumes a base saturation flow of 1900 passenger cars per hour per lane corresponding to a saturation flow headway of 1.9 sec, and provides adjustment factors for the following site factors – lane widths, heavy vehicles, grades, parking maneuvers, adjacent bus stops, pedestrian, area type and lane utilization.

In this study, we have measured base saturation flow rates for through movements at different intersections in Vermont, and attempted to group and average them by county and the number of through lanes.

Research Objective

The objectives of the study are to determine the average base saturation flow in Vermont, to determine the appropriateness of using the default value of 1900 for the base saturation flow in analysis and design calculations for the state of Vermont, i.e. if the base saturation flow rates in Vermont are close to the default 1900, and to determine if the base saturation flow varies by factors such as region and the number of through lanes.

Importance of Saturation Flow

The saturation flow rate is one of the parameters that are used to determine the Level of Service (LOS) of an intersection. The LOS depends on the average control delay experienced by vehicles. The estimated capacity of an approach depends on the saturation flow possible for the approach. According to the HCM, the predicted delay at an intersection becomes sensitive to the saturation flow when the demand reaches ninety percent of the capacity. The delay increases rapidly when the demand approaches the
capacity. Thus a good estimate of the saturation value is important when dealing with lane groups that are functioning or expected to function close to the capacity.

The estimated capacity of an approach at a signalized intersection depends on the predicted saturation flow value and the start-up lost times. The HCM equation for the capacity (c) of a lane group is the following.

\[ c = s \times \frac{g}{C} \]  

(A)

where

- \( s \) = Saturation flow rate for the lane group (veh/hour)
- \( g \) = Effective green time
- \( C \) = Cycle length.

\( g/C \) is the effective green ratio. The effective green is the Green and Yellow time minus the start-up lost time and the portion of [Yellow + All Red] that is not used.

Most software currently used in the design of signal timings use the saturation flow rate and the start-up lost time to determine the capacity of an approach. Thus a reasonably close estimate of the saturation flow and the startup lost time will provide a good start to a signal analysis or signal design project.

**Saturation Flow Rate Literature Review**

For the most part, state agencies and transportation companies use the default 1900 for the base saturation flow, and the other HCM defaults for the start-up lost time and adjustment factors, in their analyses and design. However, numerous studies have been conducted to determine the validity of assuming that these defaults could be applied to most intersections. Different studies have also been conducted to test what other factors possibly affect the saturation flow rate such as the geographical location and type of road. The following paragraph has a summary of similar studies conducted in the last few years.
A 1997 study by the Florida Department of Transportation (2) found the average base saturation flow rate to be about 1835 veh./hr./lane. They also found that the saturation flow rate varied more by the number of through lanes, rather than by county, ranging from 1670 veh/hr./lane for approaches with a single through lane to 1910 veh/hr./lane for approaches with 3 or more through lanes, and also that the saturation flow rate increases as the studied lane moves left from the right-most lane to the inner-most lane. Another study conducted in Florida (3) found that the area type adjustment factor for the area types to be 1.00 for Residential, Business and Shopping, and 0.92 for Recreational. The average saturation flow at the first three area types, close to 1900 with average saturation headway of 1.86 seconds, was taken as the base flow as they were found to not be significantly different. In another project, the same group (4) developed a procedure for obtaining driver population adjustment factors by area type, and found that non-local drivers have a significant impact on the capacity. A study conducted at the University of Vermont (5) measured the decrease in saturation flow rate during adverse weather conditions. The study found that the saturation flow rate can be decreased by as much as 20% during slushy road conditions.

McShane et al (6) suggest that when calibrating the base saturation flow rate, it may be necessary to classify approaches by facility type such as arterial, collector and local street.

**Data Collection**

The saturation flow counts were based on the guidelines provided in the HCM. The HCM states that the saturation flow rate starts when the front axle of the fourth vehicle in the queue crosses the stop line. An initial queue length of eight vehicles at the beginning of the green is required. Twenty seven intersections were chosen around the state that have a minimum impact from the other influencing factors such as lane widths, grades, adjacent parking and bus stops, turning vehicles, and pedestrian activity, and that were expected to have queue lengths of eight vehicles or more during the peak hour.
Data collection was done during the AM and PM peak hours. Exclusive through lanes or shared lanes with a very low percentage of turning vehicles were chosen. The headways were measured as the front axle of the vehicles crossed the stop line. Cycles that had a very slow vehicle or a truck in the first eight vehicles of the queue were not used. If a slow vehicle or a truck occurred in the queue after the eighth vehicle, the remainder of the queue was not used in the calculations. Cycles that had any left or right - turning vehicles also were not used. Counts were done all summer in 2003 as permitted by weather and available staffing. The average saturation flow headway for each cycle was the average of the measured headways from the fifth vehicle to the last queued vehicle. The data collection was limited by the low number of cycles that actually had a minimum of eight vehicles queued at the beginning of the green.

Over four hundred cycles of data were collected. These were tabulated along with the town code, county code, facility type and the number of approach lanes. Most of the data collected were from Chittenden and Washington counties. Adequate data were collected from Rutland and Windham counties for analysis. Other counties had to be left out of the analysis because the busiest intersections in those counties still did not generate enough traffic for queue lengths of eight or more vehicles.

**Analysis and Results**

The average headway for each cycle was calculated as a weighted average, as follows:

$$\bar{h} = \frac{t}{n}$$  \hspace{1cm} (B)

where

- $\bar{h}$ = average headway
- $t$ = length of time elapsed from the crossing of the stop bar by the fourth vehicle until to last vehicle in the queue
- $n$ = total number of vehicles in initial queue minus 4.
Since this is, in fact, an average by the Central Limit Theorem, it is normally distributed. Thus statistical analyses calling for normality, such as Student’s t-tests and Analysis of Variance (ANOVA), are applicable. The only cycles included in the analysis were those that did not have any trucks, slow-moving vehicles (tractors, construction equipment, etc.), turning vehicles or other aberrations.

Because most of the count sites were on roads of Functional Class 14 (Other Principal Arterial), it was not considered possible to conduct an analysis of saturation flow headway by facility type.

As suggested by the literature review and noted by the preliminary analysis, it was evident that there was a difference in saturation headway between 1- and 2-lane approaches. This was borne out by a t-test performed on saturation headway data aggregated on a statewide basis. Therefore, all subsequent analyses have been performed on data separated by the number of approach lanes.

To ascertain if there were any differences by location, an ANOVA was carried out on saturation flow headways using county as a grouping variable. This indicated, for 1-lane approaches, that there was no difference in saturation flow headways by location in the state. However, an ANOVA conducted on 2-lane approaches indicated that there were differences in saturation flow headways by location. Using a Scheffe post hoc test revealed that saturation flow headways could be grouped by county with Chittenden and Washington Counties representing one group and Rutland and Windham counties representing another group.

To derive aggregate saturation flow headways for these groups, the individual saturation flow headways for each cycle for each intersection in each group were averaged using a weighted average, as follows:

$$\bar{h}_c = \frac{\sum t_i}{\sum n_i}$$  \hspace{1cm} (C)

where
\[ \bar{h}_c = \text{saturation flow headway by county} \]
\[ t_i = t \text{ for each intersection (see equation B)} \]
\[ n_i = n \text{ for each intersection (see equation B)} \]

To calculate the saturation flow rate \(Q\), the following equation was used:
\[ Q = \frac{3600}{h} \]  \hspace{1cm} (D)

where:
\[ Q = \text{Saturation Flow Rate (vehs/hr)} \]
\[ h = \text{saturation flow headway (sec)} \]

Using these equations, the results of the analyses are shown in Table I.

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of lanes</th>
<th>Number of Observations</th>
<th>Average Base Headway (sec)</th>
<th>Saturation Flow Rate (Vehs./hr.)</th>
<th>Standard Saturation Flow Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statewide</td>
<td>1</td>
<td>598</td>
<td>1.99</td>
<td>1811</td>
<td>1800</td>
</tr>
<tr>
<td>Chittenden &amp; Washington</td>
<td>2</td>
<td>1461</td>
<td>1.89</td>
<td>1908</td>
<td>1900</td>
</tr>
<tr>
<td>Rutland &amp; Windham</td>
<td>2</td>
<td>222</td>
<td>2.13</td>
<td>1690</td>
<td>1700</td>
</tr>
</tbody>
</table>

**Table I Vermont Saturation Flow Headways and Rates.**

The average saturation flow rates obtained were rounded to get the standard saturation flow rates. The standard rates are shown in the last column of Table I. A series of t-tests were conducted to determine if there were any statistically significant differences between the average saturation flow rates and standard rates in Table I. None were found.

**Conclusions**

This study reveals the following conclusions:
1) There is a statistically significant difference in saturation flow headways between 1- and 2-lane approaches to signalized intersections statewide.
2) For 1-lane approaches to signalized intersections statewide the saturation flow rate to be utilized is 1800 vehs./hr.
3) For 2-lane approaches to signalized intersections in Chittenden and Washington counties the saturation flow rate to be utilized is 1900 vehs./hr.
4) For 2-lane approaches to signalized intersections in Rutland and Windham counties the saturation flow rate to be utilized is 1700 vehs./hr.

Before these rates are finalized, further research is necessary.

**Recommendations for Further Research**

Further saturation flow studies need to be conducted at appropriate intersections in southern Vermont, especially to ascertain if the regional differences noted in this study are, indeed, valid. Also, some regional and local demographic and tourism data should be examined to determine if observed differences in saturation flow rates can be explained in more detail in terms of these variables rather than in terms of regions of the state.

**References**
