Evaluation of Variable Maximum Green Time to Improve Rural Traffic Signal Operations

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ABSTRACT

Rural agencies frequently struggle to provide reasonable traffic signal operations, as they lack the financial resources and traffic expertise common to large cities. More advanced traffic signal controllers have many features which may be able to help. One such feature is variable maximum green time (VMGT) which allows the controller to continually adjust the maximum green in response to changes in traffic demand. This paper compares rural traffic signal operations given optimized timing with rural traffic signal control operations using a generic set of VMGT parameters. The research methodology included the use of software-in-the-loop simulation (SILS) with VISSIM as the traffic simulation model and the Econolite ASC/3 traffic controller software. Using one high and one low volume site, the results indicate that when compared to optimized timings, a generic set of VMGT parameters can provide equivalent throughput, nearly equivalent average intersection delays, reasonable cycle lengths, and a more equal distribution of delay among approaches and movements.
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INTRODUCTION

On April 20, 2005, the first National Traffic Signal Report Card (1) was issued by a coalition of leading transportation organizations. This evaluation of traffic signal operations was based on input from 378 state, county, and local agencies. The overall national grade of D- clearly indicates need to address several key aspects of traffic signal operations. One key issue identified in the report: a lack of regular updates to traffic signal timing.

Such poor results came as little surprise to transportation professionals. The Federal Highway Administration reports (2) that an estimated 75% of the 260,000 traffic signals in the United States could be improved “by updating equipment or by simply adjusting and updating the timing plans.” The same report indicates that poor timing is likely responsible for “5-10% of all traffic delay or 295.8 million vehicle-hours of delay each year.”

The importance of efficient traffic signal operations has increased significantly in the past two decades, as the growth of travel has greatly outpaced that of roadway capacity. From 1980 to 1998, growth in roadway capacity increased about 1% per year while travel grew by 72% (3). If agencies were able to provide proper traffic signal timing at all signalized intersections, estimates suggest that motorists could expect a 10 to 40% reduction in delay (4), up to a 10% reduction in fuel consumption, and up to a 22% reduction in harmful emissions (5).

In addition to the poor overall national grade, the Report Card also indicated that agencies responsible for very small signal systems (< 50 signals) “scored markedly lower… than larger systems.” Virtually all rural areas will fall in this category, which averaged a full letter grade lower than their larger (i.e. suburban and urban) counterparts. The primary causes of the lower grade: lack of monetary resources and lack of trained traffic personnel.

Fortunately, the continuing reduction in cost for computing capabilities has brought with it more advanced traffic signal control capabilities built into standard controllers, including many whose impact is not fully understood. One such feature is commonly referred to as a Variable Maximum Green Time (VMGT). This feature, provided on at least five control platforms by at least two different manufacturers, allows a local signal controller to determine if a phase failed to serve all waiting vehicles, and to adjust its length accordingly in subsequent cycles. The goal: improved rural traffic signal operations through real-time adaptation of signal timing to current conditions, without the typical cost or expertise required of more traditional adaptive control systems.

BACKGROUND

The operation of VMGT was defined in the NTCIP 1202 standard (6), where it was called the “dynamic max.” When enabled for a phase, the maximum green time can increase or decrease by a dynamic step each cycle based on current operations. Two consecutive max outs causes the maximum green to increase, and two consecutive gap outs causes it to decrease. The normal maximum green and dynamic maximum green determine the upper and lower bounds for the continually changing maximum, and dynamic maximum step determines the magnitude of each change. This operation is depicted graphically in Figure 1.
Engelbrecht, et al. (7) performed an early investigation of VMGT when they tested its potential to improve operations at diamond interchanges by allowing the exit ramp phase to dynamically adjust to meet surges in traffic demand caused by freeway incidents. The results of this investigation concluded that “the dynamic maximum green time feature [aka VMGT] can reduce delays and queues significantly when used on a phase controlling traffic subject to demand variations.” This investigation made use of VMGT only for the exit ramp phases – normal maximum green operation was used for all other phases.

Yun, et al. (8) performed a more thorough evaluation of VMGT, applying this method of operations to all phases, and comparing it with both a normally optimized maximum green and an arbitrarily large maximum green. As with the prior investigation, the results of this research were positive, and the authors concluded that “benefits can be achieved by utilizing the Adaptive Maximum [aka VMGT] feature over the large or optimized maximum green settings.” This research determined the variable maximum green as a function of the optimized maximum green.

This research differed from prior studies in several ways. For one, this investigation focused on the evaluation of a generic set of VMGT parameters, as opposed to basing VMGT parameters on site-specific optimized timing. These same parameters were applied to all phases in use at each intersection. In addition, where the previous studies made use of peak hour volumes, this investigation made use of 16-hour volumes (aggregated in 15-minute increments) to evaluate the continually changing performance of VMGT over an day’s traffic. Finally, the “optimal” timing plans used as a benchmark included the use of three different time-of-day maximum greens, one for off peak conditions, one for the AM peak, and another for the PM peak. This design is focused to determine if a generic set of VMGT parameters can provide operations similar to those of an optimized set of green times, but without significant cost or traffic expertise which would be unavailable to most rural agencies.

**METHODOLOGY**

Similar to the past research efforts, this study made use of simulation to evaluate VMGT applications. This provides both a “safe place” for implementation of untested timing strategies and the repeatability necessary to compare the impacts of different strategies on the same traffic conditions. Where prior studies made use of hardware-in-the-loop simulation (HILS), this research used software-in-the-loop simulation (SILS), which is a direct decedent of HILS.
HILS is the process of using and interface device to directly connect a field traffic signal controller to a traffic simulation model in order to provide more realistic signal control. Unfortunately, the inclusion of field equipment requires that all simulation be done in “real time,” drastically increasing the time required for simulation, thus reducing the practical number and duration of treatment trials. SILS, on the other hand, replaces the physical link between simulation and field controller with a software connection. The same signal controller software which would normally be present within a field controller is ported to the same computer which is running the simulation software, allowing for faster-than-real-time interaction without loss of signal control accuracy. A schematic of HILS and SILS configurations is shown below in Figure 2.

![Schematic of HILS and SILS Configurations](image)

For this project, the VISSIM (9) simulation model was coupled with the Econolite ASC/3 (10) traffic controller software to provide the platform necessary SILS environment to evaluate VMGT. Ten replications of each simulation case helped to assure the statistical validity of the results.

Two sites were chosen for study. Site 1 was a low volume site (ADT ~20,000) near Pinehurst, NC. This site had a dominant East-West traffic pattern, with mostly permitted left turns. Site 1 could be characterized as the intersection of two rural arterials, with a very small commercial development at the intersection. As such, this site experiences sharper peaks and lull periods. This is not known as a problem intersection.
Site 2 was a high volume site (ADT ~40,000) in Cookeville, TN. Traffic at this site was more balanced than Site 1, though the northbound approach carried more traffic than the others. All the approaches at Site 2 had protected-permitted phasing. Site 2 could be characterized as the intersection of a rural arterial and a rural collector-distributor, with a large regional shopping center in one quadrant of the intersection, and additional commercial development in two other quadrants. As such, this site experiences high volumes beginning mid morning and continuing throughout the day. Local residents consider this intersection to be a problem intersection, and it experiences significant queuing throughout the afternoon.

Lane configurations and associated signal phases for both sites are shown in Figure 3.

![Site 1 Lane Configuration and Associated Signal Phases](image)

![Site 2 Lane Configuration and Associated Signal Phases](image)

Note: Phases in parentheses “( )” indicate the permitted phase for protective-permitted left turns

**Figure 3  Study Site Lane Configuration and Associated Signal Phases**

Three traffic signal timing treatments were evaluated. The “default” treatment was intended to replicate conditions when no changes to the factory default maximum green times have been made. A brief survey of several controller indicated that 20 seconds is the lowest default value for maximum green time, so this was chosen for use in the project. This represents a worst case scenario.

The “optimized” treatment made use of three time-of-day maximum greens. These values were determined using the PASSER-V (11) software package. First, the AM, Mid-day, and PM peak hours were determined for each site from intersection counts. Then, these volumes were used to determine optimal timing plans using PASSER-V. The timings determined using the Mid-day volumes were used as the off-peak maximum green times (Max1). Appropriate green times were also determined using the AM peak volumes (Max2) and the PM peak volumes (Max3). The controller scheduler was used to call the Max2 and Max3 values beginning 30 minutes before and ending 30 minutes after their associated peak hour. This was intended to represent a best case scenario. It should be noted, however, that the optimized green times for Site 2 did not result in reasonable operation, so the existing green times from the field controller were used as the “best case” for this site. The green times as determined by PASSER-V, along with the existing times for Site 2, are shown in Table 1.
The initial VMGT treatment made use of the following parameters: Maximum Green = 20 seconds, Dynamic Maximum Green = 60 seconds, and Dynamic Step = 10 seconds. In a standard dual-ring, 8-phase controller, this would allow for a theoretical maximum cycle length of just over 240 seconds (240 seconds + clearance intervals), but the expectation is that not all phases will step up to the absolute maximum simultaneously, thus resulting in an expected cycle length well below the theoretical maximum. Additional VMGT treatments were to be determined and evaluated based on the results from this initial set of parameters.

**THROUGHPUT ANALYSIS**

The first performance measure of interest was throughput. Throughput was measured based on the time when a vehicle completed its trip, aggregated in 15-minute intervals. Throughput was determined for each turning movement, each approach, and the intersection as a whole. The intersection throughput results are shown for Site 1 in Figure 4 and for Site 2 in Figure 5. The approach and movement level throughputs showed similar patterns. The standard deviation of each data point is shown using the vertical range bars on the charts.

<table>
<thead>
<tr>
<th></th>
<th>Max</th>
<th>Peak</th>
<th>Times</th>
<th>Maximum Green for Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max1</td>
<td>Off</td>
<td>all others</td>
<td>1</td>
</tr>
<tr>
<td>Site 1</td>
<td>Max2</td>
<td>AM 7:00 - 9:00</td>
<td>-</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Max3</td>
<td>PM 16:00 - 18:00</td>
<td>-</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Max1</td>
<td>Off</td>
<td>all others</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Max2</td>
<td>AM 9:15 - 11:15</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Max3</td>
<td>PM 15:15 - 17:15</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Site 2</td>
<td>Existing</td>
<td>Runs All Day</td>
<td>45</td>
<td>60</td>
</tr>
</tbody>
</table>
At Site 1, the low volume site, all the signal treatments maintained equal throughput except during the AM peak. During this time, the throughput of both the optimized and the VMGT treatments is clearly higher than the default. There is no significant difference between the optimized and VMGT treatments at any time during the day.
At Site 2, the high volume site, the differences were more pronounced. From about 9:30 to 17:30, differences in throughput begin to show. These differences are most pronounced between 13:00 and 18:00, so a zoomed view of this time period is shown in Figure 6.

Figure 5  Site 2 Intersection Throughput (veh/15min)
During the intervals shown in Figure 6, the general trend is that the existing and VMGT treatments are consistently serving more volume than the default treatment. In several of the 15-minute intervals, there is no overlap between the standard deviation ranges of the existing or VMGT treatment with the ranges of the default treatment. And while the standard deviations do overlap, indicating the difference may not be significant, the VMGT treatment is slightly higher than the existing for the majority of the intervals shown.

From these results, a traffic signal using the generic VMGT settings is capable of serving the vehicle demand at the test sites.

**DELAY ANALYSIS**

Given similar throughputs, the next performance measure of interest was delay. As with throughput, the delay for a 15-minute interval was based on the delay experienced by vehicles completing their trip during that interval. The average intersection delay for Site 1 is shown in Figure 7, and the average intersection delay for Site 2 is shown later in Figure 8.
As would be expected at a low volume site, the delay results from Site 1 indicate reasonable operations for the majority of the day regardless of signal treatment. The only time period that appears to have significant differentiation in delays is the AM peak, where both the optimized and VMGT signal outperform the default, and where the optimized also outperforms the VMGT, though by a smaller margin. A numerical analysis of the AM peak showed that the optimized treatment reduced delay by 43% over the peak hour, and by 40% during the peak 15 minutes. During these same intervals, the VMGT treatment reduced delay by 29% over the peak hour, and by 23% during the peak 15 minutes.
In accordance with its higher volumes, Site 2 experiences significantly more delay than Site 1, and also experiences greater differentiation in delay between treatments. All three treatments perform reasonably similar until about 9:00, after which both the existing and the VMGT provide for improved operations when compared to the default. During the majority of the afternoon, the existing timing provides for better performance than the VMGT, however there are periods, most notably in the early evening, when the VMGT provides for better operations than the existing. A more detailed numerical analysis of the delay results is provided in Table 2. Note that in the table, negative values indicate a reduction in delay.

Table 2 Numerical Analysis of Average Intersection Delay for Site 2

<table>
<thead>
<tr>
<th></th>
<th>Morning</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Full Interval</td>
<td>Peak Hour</td>
<td>Peak 15-min</td>
<td>Full Interval</td>
<td>Peak Hour</td>
<td>Peak 15-min</td>
<td>Full Interval</td>
<td>Peak Hour</td>
<td>Peak 15-min</td>
<td>Full Interval</td>
<td>Peak Hour</td>
</tr>
<tr>
<td>Start Time</td>
<td>6:00</td>
<td>7:30</td>
<td>7:45</td>
<td>10:00</td>
<td>11:30</td>
<td>13:15</td>
<td>14:00</td>
<td>16:30</td>
<td>17:15</td>
<td>18:00</td>
<td>18:00</td>
</tr>
<tr>
<td>End Time</td>
<td>10:00</td>
<td>8:30</td>
<td>8:00</td>
<td>14:00</td>
<td>12:30</td>
<td>13:30</td>
<td>18:00</td>
<td>17:30</td>
<td>22:00</td>
<td>19:00</td>
<td>18:15</td>
</tr>
<tr>
<td>Avg Delay (sec/veh)</td>
<td>Default</td>
<td>41.1</td>
<td>76.1</td>
<td>140.3</td>
<td>101.3</td>
<td>104.4</td>
<td>132.6</td>
<td>141.2</td>
<td>149.0</td>
<td>143.4</td>
<td>53.8</td>
</tr>
<tr>
<td></td>
<td>VMGT</td>
<td>36.3</td>
<td>64.2</td>
<td>113.9</td>
<td>89.6</td>
<td>94.7</td>
<td>114.9</td>
<td>103.7</td>
<td>114.0</td>
<td>109.2</td>
<td>34.3</td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>38.5</td>
<td>62.2</td>
<td>107.0</td>
<td>87.6</td>
<td>89.7</td>
<td>99.3</td>
<td>92.5</td>
<td>102.4</td>
<td>100.7</td>
<td>40.6</td>
</tr>
<tr>
<td>Delay Difference (sec/veh)</td>
<td>Existing - Def</td>
<td>-4.6</td>
<td>-13.9</td>
<td>-33.4</td>
<td>-13.7</td>
<td>-14.7</td>
<td>-33.3</td>
<td>-48.7</td>
<td>-46.6</td>
<td>-42.7</td>
<td>-13.2</td>
</tr>
<tr>
<td></td>
<td>VMGT - Def</td>
<td>-6.5</td>
<td>-11.9</td>
<td>-26.4</td>
<td>-11.6</td>
<td>-9.7</td>
<td>-17.7</td>
<td>-37.5</td>
<td>-35.0</td>
<td>-34.2</td>
<td>-19.5</td>
</tr>
<tr>
<td></td>
<td>VMGT - Exist</td>
<td>-9.2</td>
<td>1.9</td>
<td>7.0</td>
<td>2.1</td>
<td>5.0</td>
<td>15.6</td>
<td>11.3</td>
<td>11.6</td>
<td>8.8</td>
<td>-4.3</td>
</tr>
<tr>
<td>Percent Difference</td>
<td>Existing - Def</td>
<td>-11%</td>
<td>-18%</td>
<td>-24%</td>
<td>-14%</td>
<td>-14%</td>
<td>-25%</td>
<td>-35%</td>
<td>-31%</td>
<td>-30%</td>
<td>-25%</td>
</tr>
<tr>
<td></td>
<td>VMGT - Def</td>
<td>-12%</td>
<td>-18%</td>
<td>-19%</td>
<td>-11%</td>
<td>-9%</td>
<td>-13%</td>
<td>-27%</td>
<td>-23%</td>
<td>-24%</td>
<td>-36%</td>
</tr>
<tr>
<td></td>
<td>VMGT - Exist</td>
<td>0%</td>
<td>3%</td>
<td>5%</td>
<td>2%</td>
<td>5%</td>
<td>12%</td>
<td>8%</td>
<td>8%</td>
<td>6%</td>
<td>-12%</td>
</tr>
</tbody>
</table>
Based on these results, the generic VMGT parameters can provide for reasonable operation, even at this high volume intersection. In all but the midday 15-minute peak, the delay result from the VMGT treatment is no more than 10% higher than the existing treatment, and during the evening interval, VMGT provided the best operations.

There is more to delay than just the average intersection value. While this value can give insight into overall intersection operations, there are other considerations like an equitable distribution of delay. To this end, Figure 9 displays the average delay per vehicle for the worst approach in each interval.

**Figure 9  Site 2 Worst Approach Average Delay (sec/veh)**

For the majority of the day, the VMGT treatment provides for the lowest “worst approach” delay per vehicle. Given its reasonable equivalence to the existing in average intersection delay, this indicates that the VMGT treatment is providing a more equal distribution of delay among the approaches. The identical trend is present when evaluating the worst movement delay at the intersection.

**SIGNAL ANALYSIS**

One of the concerns mentioned above is the potential for VMGT to result in an excessive cycle lengths, as the theoretical maximum cycle for Site 2 is 240 seconds. Assuming traffic is heavy enough to cause the signal to cycle through it’s phases, it is possible to approximate the cycle length in any 15-minute interval by determining the maximum number of times any phase terminates during the interval. Based on this method,
Despite traffic heavy enough to result in Level of Service F conditions, the cycle length did not spiral up to its theoretical maximum, though it did result in slightly longer cycles than the existing treatment. As expected, while the traffic volume did cause individual phases to increase, natural fluxuations within the traffic flow prevented all the phases from simultaneously increasing to the variable maximum green.

For the most part, the individual phases followed reasonable trends, with the notable exception of phase 4, which is discussed in more detail in the next section.

**POSSIBLE MODIFICATIONS TO THE GENERIC VMGT PARAMETERS**

While the initial set of generic VMGT parameters performed well in comparison to the other treatments evaluated, there was an attempt to determine if different parameters could provide for better operations. Two different modifications were considered.

First, when reviewing the Site 1 cycle length estimates, the VMGT cycle length was noticeably lower than the optimized during the same AM peak intervals when the VMGT delay was higher than the optimized. Because the traffic demand at Site 1 includes such a sharp AM peak, a larger dynamic maximum step of 20 seconds (instead of the original 10) was evaluated at Site 1. The larger step size did not improve performance over the original 10 second step – essentially no differences in throughput, delay, or cycle length were noted.

Second, when reviewing the individual average phase lengths for Site 2, the average length of phase 4 (eastbound through and right) was at or near the variable maximum green of 60 seconds from 10:00 to 17:00. During this same time interval, the intersection is typically experiencing Level of Service F. Given these, a larger dynamic maximum
green of 100 seconds (as opposed to 60 seconds) was evaluated at Site 2. While both the throughput and the average intersection delay remained essentially the same as with the original dynamic maximum green, the larger dynamic maximum did result in significant changes in worst approach average delay and in apparent cycle length.

As would be expected, increasing the dynamic maximum allowed for longer cycle lengths, sometimes as much as 80 to 90 seconds longer than those of the original VMGT treatment. As noted above, these longer cycle lengths did not result in an improvement in average intersection delay; however, they did result in significantly lowering the worst approach average delay, thus providing an even more equal distribution of delays between approaches.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to determine if a generic set of VMGT parameters can provide operations similar to those of an optimized set of green times, but without significant cost or traffic expertise which would be unavailable to most rural agencies. The research made use of SILS techniques using the VISSIM simulation model and the Econolite ASC/3 traffic controller software to determine the expected performance of a default set of timing parameters, an optimized set of timing parameters, and a generic set of VMGT parameters, namely a maximum green of 20 seconds, a dynamic maximum green of 60 seconds, and a dynamic maximum step of 10 seconds.

Based on comparisons at two sites, a low volume and a high volume site, the analyses indicate that…

• The generic VMGT treatment proved able to serve equivalent traffic volumes as an optimized signal. At both sites, the intersection throughput of the VMGT and the optimized or existing treatments were equivalent.
• The generic VMGT treatment provide able to provide similar average intersection delays to an optimized signal. At Site 1, the delays were essentially identical, except for the sharp AM peak, when the optimized signal performed better. At Site 2, the delays were similar throughout the day, with periods when the existing treatment performed better and periods when the MVGT treatment performed better.
• The generic VMGT treatment can provide for a more equitable distribution of delay. At Site 1, the worst approach delays were essentially the same for the optimized and VMGT treatments. At Site 2, however, the VMGT treatment provided for a significantly lower worst approach delay than the existing treatment.
• The generic VMGT treatment will provide reasonable traffic signal operations. At Site 1, the VMGT treatment typically resulted in a lower cycle length than the optimized. At Site 2, the VMGT treatment resulted in cycle lengths that were comparable to those of the existing treatment, with both periods of lower and higher cycle length than the existing treatment. The cycle length did not increase to the theoretical maximum at either site.
• An increased dynamic maximum step size did not significantly change the performance. This option was tested on Site 1, with no differences noted.
• An increased dynamic maximum green did result in a longer cycle length, and in a more equal distribution of delay among approaches and movements. This option was tested on Site 2. Essentially, this allows individual agencies to select a dynamic maximum green time based on their cycle length preferences.

As will all simulation-based research, the next logical step is a field evaluation of these VMGT settings. Additional work could include study of additional sites, especially with fully protected left turns and moderate volumes.

ACKNOWLEDGEMENT

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