Chapter 6- Application and Results

6.1. Application

The above proposed methodology is applied to an arterial street network made up of three links. A loop detector is placed at the 800 ft mark from the stop line of each link. The length of main link i is 1600ft.

The traffic data is obtained from the loop detector as simulated by CORSIM. The travel times on the main link i are calculated based on the data from the loop detector. The conditions on link i are affected by the conditions on link i+1 and link i-1.

Three different time interval updates by the loop detector are carried on to test the sensitivity of the results to various time updates based on the same intersection cycle length of 100 seconds and with the same incoming volumes. The three time updates are 60sec, 100 sec and 120 sec respectively. The first simulation is based on a time interval update of 100 seconds, which also represents the observed cycle length of the downstream intersection of link i.

The loop detector in CORSIM provides three types of traffic data: the cumulative number of vehicle passing the detector, the cumulative average speed detected by the detector (mph), and the cumulative dwelling time (sec). Based on these data, the average dwelling time during the observed time interval is calculated as follows:

\[
\frac{\text{Total dwelling time during observed interval}}{\text{number of vehicle counted during observed interval}};
\]

The density Ktd is calculated as the ratio of flow/speed.
The cycle length for the observed intersection is 100 sec with 60 seconds green time in the observed direction. The free flow speed (speed limit) is 45 mph. There is a left turn pocket lane on link i. The layout information of the experiment is shown in Figures 6-1 and 6-2. Figure 6-2 shows the CORSIM visualization simulation output for the main link. The saturated departure flow rate in green time is simulated by CORSIM to be 1800 veh/h/ln. The intersection capacity is 1800*60/100=1080 veh/h/ln. And the capacity of link i-1 is 1395veh/h/ln, since the green time is 75 seconds out of a 100 seconds cycle length.

![Figure 6 - 1 Arterial Streets Network in CORSIM](image1)

![Figure 6 - 2 Vision of Simulation in CORSIM](image2)
6.2 The analysis for 100 sec. time interval.

The input volume is shown in Table 6-1 as it is fed into the CORSIM simulator:

<table>
<thead>
<tr>
<th>100 sec interval</th>
<th>Volume(veh/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–100</td>
<td>900</td>
</tr>
<tr>
<td>100–200</td>
<td>2550</td>
</tr>
<tr>
<td>200–300</td>
<td>3900</td>
</tr>
<tr>
<td>300–400</td>
<td>5400</td>
</tr>
<tr>
<td>400–500</td>
<td>5100</td>
</tr>
<tr>
<td>500–600</td>
<td>4200</td>
</tr>
<tr>
<td>600–700</td>
<td>3000</td>
</tr>
<tr>
<td>700–800</td>
<td>1200</td>
</tr>
<tr>
<td>800–900</td>
<td>900</td>
</tr>
<tr>
<td>900–1000</td>
<td>600</td>
</tr>
<tr>
<td>1000–1100</td>
<td>600</td>
</tr>
</tbody>
</table>

The data collected from the loop detector in CORSIM is shown in Table 6-2:

<table>
<thead>
<tr>
<th>Time period</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>cumulative number of vehicle detected (3 lanes)</td>
<td>cumulative average speed by detector (mph)</td>
<td>cumulative dwelling time (secs)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>73</td>
<td>38.3</td>
<td>24.9</td>
</tr>
<tr>
<td>2</td>
<td>134</td>
<td>39.3</td>
<td>44.3</td>
</tr>
<tr>
<td>3</td>
<td>227</td>
<td>38.6</td>
<td>74.5</td>
</tr>
<tr>
<td>4</td>
<td>337</td>
<td>38.1</td>
<td>109.4</td>
</tr>
<tr>
<td>5</td>
<td>474</td>
<td>36.7</td>
<td>156.1</td>
</tr>
<tr>
<td>6</td>
<td>580</td>
<td>34.3</td>
<td>210.1</td>
</tr>
<tr>
<td>7</td>
<td>684</td>
<td>30.9</td>
<td>284.8</td>
</tr>
<tr>
<td>8</td>
<td>754</td>
<td>28.8</td>
<td>369</td>
</tr>
<tr>
<td>9</td>
<td>782</td>
<td>28.7</td>
<td>387.2</td>
</tr>
<tr>
<td>10</td>
<td>807</td>
<td>29.1</td>
<td>395.2</td>
</tr>
</tbody>
</table>
The data calculated for each time interval using Table 6-2 is shown in Table 6-3.

### Table 6-3 Data Transfer From Loop Detector

<table>
<thead>
<tr>
<th>Time period</th>
<th>Detector (veh /cycle length/ln) count</th>
<th>average speed by detector (mile /h)</th>
<th>Occupancy (%)</th>
<th>Density Ktd (veh/mile)</th>
<th>average dwelling time sec/veh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.3</td>
<td>38.3</td>
<td>8.3</td>
<td>22.9</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>20.3</td>
<td>40.5</td>
<td>6.5</td>
<td>18.1</td>
<td>0.32</td>
</tr>
<tr>
<td>3</td>
<td>31</td>
<td>37.6</td>
<td>10.1</td>
<td>29.7</td>
<td>0.32</td>
</tr>
<tr>
<td>4</td>
<td>36.7</td>
<td>37.1</td>
<td>11.6</td>
<td>35.6</td>
<td>0.32</td>
</tr>
<tr>
<td>5</td>
<td>45.7</td>
<td>33.3</td>
<td>15.6</td>
<td>49.4</td>
<td>0.34</td>
</tr>
<tr>
<td>6</td>
<td>35.3</td>
<td>23.6</td>
<td>18</td>
<td>54</td>
<td>0.51</td>
</tr>
<tr>
<td>7</td>
<td>34.7</td>
<td>11.9</td>
<td>24.9</td>
<td>104.5</td>
<td>0.72</td>
</tr>
<tr>
<td>8</td>
<td>23.3</td>
<td>8.3</td>
<td>28.1</td>
<td>101.4</td>
<td>1.2</td>
</tr>
<tr>
<td>9</td>
<td>9.3</td>
<td>26</td>
<td>6.1</td>
<td>12.9</td>
<td>0.65</td>
</tr>
<tr>
<td>10</td>
<td>8.3</td>
<td>41.6</td>
<td>2.7</td>
<td>7.2</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Column 1 in Table 6-3 is obtained by using column A in Table 6-2 as follows:

$$\frac{(A_t) - (A_{t-1})}{3}.$$  
For example, at time interval 1 in Table 6-3, the number of vehicles detected is \((73-0)/3=24.33\) veh/ln/cycle length, where 3 represents the number of lanes.

The average speed at time t in Table 6-3 is calculated using columns A and B in Table 6-2 as follows;  

$$\frac{A_t \times B_t - A_{t-1} \times B_{t-1}}{A_t - A_{t-1}} \text{ (mph)};$$

The average dwelling time is calculated using columns C and A as follows;  

$$\frac{C_t - C_{t-1}}{A_t - A_{t-1}} \text{ (sec/veh)};$$

The average occupancy at the detector= (average dwelling time)*CL/3600*100%;
Density (Ktd) at time t = \( \frac{(A_t) - (A_{t+1})}{3} \times \frac{3600}{CL} \times \frac{\text{speed in table 3}}{} \), (veh/mile)

In this experiment the travel time update is equal to the cycle length which is 100 secs.

So, we chose 10 travel time updates for a total of 1000 secs., and consequently the CORSIM simulation is run for 1000 secs. We found out that 1000 secs were enough for the vehicle queue to build up to reach the detector and to completely dissipate within this period.

**Travel Time for Time Interval 1:**

In the first time interval, there is no initial queue. From Table 6-3, the detected volume is 24.33 veh/ln. These 24.33 veh are the observed group whose travel time to traverse link i is to be computed for time interval 1. The average speed detected by detector is 38.3 mph.

The Volume in an hour as opposed to 100 secs is: \( \frac{24.33}{100} \times 3600 = 876 \) vph;

\[ \text{V/C} = \frac{876}{1080} = 0.811; \]

The density is \( \text{Ktd} = \frac{\text{flow}}{\text{speed}} = \frac{24.33}{100} \times 3600 / 38.3 = 22.87 \text{ veh/mile}; \]

\[ h_1 = \frac{100}{24.3} = 4.11 \text{ sec/veh} \]

\[ h_2 = 2 \text{ sec/veh} \]

\[ S_1 = 38.3 \text{ mph}, S_2 = 6.5 \text{ mph} \]

\[ t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{38.3 \times 4.11 - 19}{38.3 - 6.5} = 4.35; \]

\[ h_3 = \frac{t \times h_2}{t - h_2} = \frac{4.35 \times 2}{4.35 - 2} = 3.7 \text{ sec/veh} \]

From Equation 4-14, the average uniform stopped delay for this observed group is computed as follows:
The over-saturation delay is zero since $V$ is smaller than the intersection capacity $d_2 = 0$.

The initial queue $d_3$ is equal to zero since there is no initial queue at this time period.

$$W_d = \frac{C - V}{k_q - k_{sl}} = \frac{1080 - 876}{135 - 22.87} = 1.82 \text{mile/hour}$$

The queuing rate $QR(\text{veh/h})$ is:

$$QR = \frac{dn}{dt} = (V - C - W_d \times k_a) = (876 - 1080 - 1.82 \times 22.87) = -245.6 \text{veh/h}$$

The number of vehicles in the queue which is built during the observed cycle length $t$ will be:

$$Q_m = QR \times CL = -245.6 \times \frac{100}{3600} = -7 \text{veh}$$

Then the initial queue for the next time interval is $Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 0$.

Hence, from Equation 3-9 the travel time for this group is:

$$\text{Travel - time} = \frac{L - QL}{\text{speed by detector}} + d_1 + d_2 + d_4$$

$$= \frac{1600 - 0}{38.3 \times 5280 \div 3600} + 15.2 + 0 + 0 = 43.7 \text{ sec}$$

Hence, the travel time in time interval 1 is 43.7 sec., and the initial queue for next time interval is zero.

**Travel Time for Time Interval 2:**

In the second time interval, there is no initial queue based on the previous computation, and the average dwelling time 0.32sec/veh is smaller than 0.6sec/veh.
Hence, there is no blackout on the loop detector. From Table 6-3, the detected volume is 20.33 veh/ln. These 20.33 veh is the observed group whose travel time is to be computed for time interval 2. The average speed detected by detector is 40.5mph.

Volume: \( \frac{20.33 \times 3600}{100} = 732 \text{ vph} \);

\( \frac{V}{C} = \frac{732}{1080} = 0.678; \)

The density is \( K_{td} = \frac{\text{flow}}{\text{speed}} = \frac{20.33 \times 3600}{40.5} = 18.1 \text{ veh/mile} \);

\( h_1 = \frac{100}{20.3} = 4.9 \text{ sec/veh} \)

\( h_2 = 2 \text{ sec/veh} \)

\( S_1 = 40.49 \text{ mph}, S_2 = 6.5 \text{ mph} \)

From Equation 4-13;

\[
t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{40.49 \times 4.9 - 19}{40.49 - 6.5} = 5.3;
\]

\[
h_3 = \frac{t \times h_2}{t - h_2} = \frac{5.3 \times 2}{5.3 - 2} = 3.21 \text{ sec/veh};
\]

From Equation 4-14, the average uniform stopped delay for this observed group is computed as follows:

\[
d_1 = \frac{0.5 \times Q_{max} \times Q_r}{Total \_arrival} = \frac{0.5 \times \frac{40}{4.9} \times \left( \frac{40}{4.9} \times 3.21 + 40 \right)}{20.3} = 13.2 \text{ sec/veh};
\]

The over-saturation delay is zero since \( V \) is smaller than intersection capacity

\( d_2 = 0; \)

Since there is no initial queue for this incoming group, the initial queue \( d_3 = 0 \text{ sec.} \)

\[
W_d = \frac{C - V}{k_q - k_{id}} = \frac{1080 - 732}{135 - 18.1} = 2.97 \text{ mile/hour};
\]

The queuing rate \( Q_R \text{(veh/h)} \) is:
QR = \frac{dn}{dt} = (V - C - W_d \times k_d) = (732 - 1080 - 2.97 \times 18.1) = -401.8\text{veh/h}

The number of vehicles in queue which is built during the observed cycle length t will be:

\[ Q_m = QR \times CL = -401.8 \times \frac{100}{3600} \approx -11\text{veh/ln} \]

Then the initial queue for the next time interval is \( Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 0 \).

Hence, from Equation 3-9, the travel time for this group is:

\[
\text{Travel-time} = \frac{L - QL}{\text{speed by detector}} + d1 + d2 + d4
\]

\[
= \frac{1600 - 0}{40.49 \times 5280 / 3600} + 13.2 + 0 + 0 = 40.1\text{sec}
\]

Therefore, the travel time for time interval 2 is 40.1 sec, and the initial queue for the next time interval is zero.

**Travel Time for Time Interval 3:**

In third time interval, there is no initial queue based on the calculation of the previous time period 2, and the average dwelling time 0.32sec/veh is smaller than 0.6sec/veh. Hence, there is no blackout on the loop detector. From Table 6-3, the detected volume is 31 veh/ln. The average speed detected by detector is 37.59 mph.

Volume: 31/100*3600=1116vph;

\[ V/C=1116/1080=1.033; \]

The density is \( Ktd = \text{flow/speed} = 31/100*3600/37.59 = 29.7 \text{ veh/mile}; \)

Since, V is greater than C, use the capacity as the input volume to estimate the uniform stopped delay d1:

\[ h1=100/30=3.33 \text{ sec/veh} \]
h2 = 2 sec/veh

S1 = 37.6 mph, S2 = 6.5 mph;

From Equation 4-13;

\[ t = \frac{S1 \times h1 - 19}{S1 - S2} = \frac{37.6 \times 3.33 - 19}{37.6 - 6.5} = 3.42; \]

\[ h3 = \frac{t \times h2}{t - h2} = \frac{3.42 \times 2}{3.42 - 2} = 4.82 \text{ sec/veh} \]

From Equation 4-14, the average uniform stopped delay for this observed group is computed as follows:

\[ d1 = 0.5 \times \frac{Q_{max} \times Q_t}{Total \arrival} = \frac{0.5 \times \frac{40}{3.3} \times \left( \frac{40}{3.3} \times 4.82 + 40 \right)}{31} = 18.9 \text{ sec/veh}; \]

Since there is no initial queue for this incoming group, the initial queue d3 = 0 sec.

\[ W_u = \frac{V - C}{k_d - k_q} = \frac{1116 - 1080}{29.7 - 135} = -0.34 \text{ mile/hour} \]

The queuing rate QR (veh/h) is:

\[ QR = \frac{dn}{dt} = (V - C - W_u \times k_u) = (1116 - 1080 + 0.34 \times 29.7) = 46.1 \text{ veh/h} \]

The number of the vehicles in queue which is built during the observed cycle length t will be:

\[ Q_m = QR \times CL = 46.1 \times \frac{100}{3600} \approx 1 \text{ veh/ln} \]

Then the initial queue for the next time interval is \( Q_{r-1} = \max(0, \sum_{m=1}^{t} Q_m) = 1 \text{ veh/ln} \).

The initial queue for next time interval is 1 veh.

The queue length is

\[ (19) \times 1 = 19 \text{ ft} \]
Since $Q_m$ is greater than zero, there is an over-saturation delay. From Equation 4-27,

$$d_2 = \frac{area(B) + area(C)}{V \times CL} = \frac{0.5 \times Q_m \times CL}{V \times CL} + \frac{0.5 \times Q_m \times Q_m \times h2}{V \times CL} + \frac{Q_m \times r}{V \times CL}$$

$$= \frac{0.5 \times 1 \times 100}{31} + \frac{0.5 \times 1 \times 1 \times 2}{31} + \frac{1 \times 40}{31} = 2.9 \text{ sec}$$

According to Equation 3-10, the travel time for this group is computed as follows:

$$Travel\ -\ time = \frac{L_{TD} - QL}{\text{speed}_by\_loop\_detector\times 2} + \frac{L - L_{TD}}{\text{speed}_limit} + d1 + d2 + d4$$

$$= \frac{800 - 19}{37.5 \times \frac{3600}{5280} \times 2} + \frac{800}{45 \times \frac{3600}{5280}} + 18.9 + 2.9 + 0 = 41.2 \text{ sec}$$

Therefore, the travel time for time interval 3 is 41.2 sec., and the initial queue for the next time interval is one vehicle.

**Travel Time for Time Interval 4**

In time interval 4, there is an initial queue based on the calculation of the previous time periods, and the average dwelling time at the detector is smaller than 0.6 sec/veh. Hence, there is no blackout on the loop detector. From Table 6-3, the detected volume is 36.66 veh/ln. These 36.66 veh represent the observed group whose travel time is to be calculated for time interval 4. The average detected speed is 37.01 mph.

Volume: $36.66/100*3600=1320vph$;

$\text{V/C}=1320/1080=1.222$;

The density is $K_{td} = \text{flow/speed}=36.66/100*3600/37.01=35.67 \text{ veh/mile}$;

Since, $V$ is greater than $C$, use the capacity as the input volume to estimate the uniform stopped delay $d_1$.

$h_1=100/30=3.33 \text{ sec/veh}$
\( h_2 = 2 \text{ sec/veh} \)

\( S_1 = 37. \text{ mph}, S_2 = 6.5 \text{ mph} \)

From Equation 4-8, \((n - 1) \times g \leq \frac{Q_{t-1}}{D_s} \leq n \times g\);

Since \( \frac{Q_{t-1}}{D_s} = \frac{1}{1800 \div 3600} = 2 \text{ sec}, \text{ and } g = 60, n = 1 \)

From Equation 4-9, the initial delay is

\[ d_3 = \frac{Q_{t-1}}{D_s} + (n) \times \text{ red time} = \frac{1}{1800 \div 3600} + (1) \times 40 = 42 \text{ sec} \]

\[ W_u = \frac{V - C}{k_d - k_q} = \frac{1320 - 1080}{35.67 - 135} = -2.41 \text{ mile/hour} \]

The queuing rate \( QR(\text{veh/h}) \) is:

\[ QR = \frac{dn}{dt} = (V - C - W_u \times k_u) = 326 \text{ veh/h} \]

The number of vehicles in the queue which is built during the observed cycle length \( t \) will be:

\[ Q_m = QR \times CL \approx 9 \text{ veh/ln} \]

Then the initial queue for the next time interval is

\[ Q_{t-1} = \max(0, \sum_{m=1}^{i} Q_m) = 1 + 9 = 10 \text{ veh/ln} \]

In this time interval, \( d_3 \) is smaller than the cycle length and volume is greater than the capacity. Figure 4-17 and its corresponding equations, as shown in Chapter 4, are used to compute the \( d_1 \) in this time interval.

From Equation 4-13 to 2-15;
Based on Figure 4-17 and equations from Equation 4-15 to 2-19, we can get:

\[ g_1 = 2 \text{ sec}, \quad \text{and} \quad g_2 = 58 \text{ sec} \]

\[ L = m + Iq - \frac{g_1 + g_2}{h_3} = 12 + 1 - \frac{2}{4.82} = 12.6 \]

\[ i = 1 \]

\[ t_4 - t_3 = (i - L) \times h_1 = (1 - 0.55) \times 3.33 = 1.5 \text{ sec} \]

\[ a = 0.5 \times (k + L) \times g_2 = 0.5 \times (12.6 + 0.55) \times 58 = 380 \text{ sec} \]

\[ b = 0.5 \times (L + i) \times (t_4 - t_3) + i \times (red - (t_4 - t_3)) \]
\[ = 0.5 \times (0.55 + 1) \times 1.5 \times (40 - 1.5) = 40 \text{ sec} \]

\[ c = 0.5 \times i \times i \times h_2 = 0.5 \times h_2 \times i^2 = 0.5 \times 2 = 1 \]

The average stopped delay is computed as follows

\[ d_1 = \frac{a + b + c}{V \times CL} = \frac{380 + 40 + 1}{37} = 11.5 \text{ sec} \]

Since, \( Qm \times h_2 \) is smaller than \( g_2 \), Over-saturation delay is computed as follows:

\[ d_2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} = \frac{0.5 \times 9 \times 100}{36.7} + \frac{0.5 \times 9 \times 9 \times 2}{36.7} = 14.5 \]

Since \( d_3 \) is smaller than cycle length and the volume is greater than the capacity

Equation 4-29 and 4-30 are used to compute the \( d_4 \). And the new value of \( k \) and \( m \) should be computed based on the actual volume which is 36.7 veh per 100 seconds.

The \( k' \) and \( m' \) is 15.4 and 14.6 respectively.
\[
d4 = \frac{0.5 \times r \times m' + 0.5 \times (m' + k') \times g1}{\text{Total vehicle in the Observed Group}}
\]
\[
= \frac{0.5 \times 40 \times 14.6 + 0.5 \times (14.6 + 15.4) \times 2}{36.7} = 8.8 \text{ sec}
\]

\[
\text{Travel time} = \frac{L_{TD} - QL}{\text{Speed by detector} \times 2} + \frac{L - L_{TD}}{\text{Speed limit}} + d1 + d2 + d4
\]
\[
= \frac{800 - 19 \times 1}{37.06 \times 5280 \div 3600} + \frac{1600 - 800}{45 \times 5280 \div 3600} + 11.5 + 14.5 + 8.8 = 61.3 \text{ sec}
\]

Hence, the travel time for time interval 4 is 61.3 sec. The initial queue for next time interval is 10 veh.

**Travel Time for Time Interval 5**

In time interval 5, there is an initial queue of 10 veh, and the average dwelling time at the detector is 0.34 sec/veh which is smaller than 0.6 sec/veh. Hence, there is no blackout at the loop detector. From Table 6-3, the detected volume is 45.66 veh/hr, and the average detected speed is 33.25 mph.

Volume: \(45.66 / 100 \times 3600 = 1644 \text{ vph}\);

\(V/C = 1644 / 1080 = 1.522\);

The density is \(K_{td} = \text{flow/speed} = 1644 / 33.25 = 49.43 \text{ veh/mile}\);

From Equation 4-8, \((n - 1) \times g \leq \frac{Q_{t-1}}{D_s} \leq n \times g\);

Since \(\frac{Q_{t-1}}{D_s} = \frac{10}{1800 \div 3600} = 20 \text{ sec}\), and \(g = 60\), \(n = 1\)

From Equation 4-8, the initial delay is

\[d3 = \frac{Q_{t-1}}{D_s} + (n \times \text{red time}) = \frac{10}{1800 \div 3600} + (1) \times 40 = 60 \text{ sec}\]

\(g1 = 20 \text{ sec}\), and \(g2 = 40 \text{ sec}\)

Since \(V\) is greater than Capacity, use the capacity as the incoming volume to estimate
the uniform stopped delay.

\[ h_1 = \frac{100}{30} = 3.33 \text{ sec/veh} \]

\[ h_2 = 2 \text{ sec/veh} \]

\[ S_1 = 33 \text{ mph, } S_2 = 6.5 \text{ mph} \]

\[ W_u = \frac{V - C}{k_{id} - k_q} = \frac{1644 - 1080}{49.43 - 135} = -6.6 \text{ mile/hour} \]

The queuing rate \( QR \) (veh/h) is:

\[ QR = \frac{dn}{dt} = (V - C - W_q \times k_q) = (1644 - 1080 + 6.6 \times 49.43) = 900 \text{ veh/h} \]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[ Q_m = QR \times CL = 900 \times \frac{100}{3600} \approx 24 \text{ veh/ln} \]

Then the initial queue for the next time interval is

\[ Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 10 + 24 = 34 \text{ veh/ln} \]

The queue length is \( 19 \times 34 = 646 \text{ ft} \)

In time interval 5, the \( d_3 \) is smaller than the cycle length and volume is greater than the intersection capacity. Figure 4-17 and its corresponding equations, as shown in Chapter 4, are used to compute the \( d_1 \) in this time interval.

From Equation 4-13 to 2-15, we can get

\[ t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{33 \times 3.33 - 19}{33 - 6.5} = 3.4; \]

\[ h_3 = \frac{t \times h_2}{t - h_2} = \frac{3.4 \times 2}{3.4 - 2} = 4.82 \text{ sec/veh} \]

\[ m = \frac{r}{h_1} = \frac{40}{3.33} = 12 \text{ veh} \]

\[ k = m + Iq - \frac{g_1}{h_3} = 12 + 10 - \frac{20}{4.82} = 17.8 \]
\[ L = m + Iq - \frac{g_2 h^2}{h^3} = 12 + 10 - \frac{60}{4.82} = 9.5; \]

\[ i = 10 \]

\[ t_4 - t_3 = (i - L) \times h_1 = (10 - 9.5) \times 3.33 = 1.6 \]

\[ a = 0.5 \times (k + L) \times g_2 = 0.5 \times (17.8 + 9.5) \times 40 = 546 \text{ sec} \]

\[ b = 0.5 \times (L + i) \times (t_4 - t_3) + i \times (red - (t_4 - t_3)) \]

\[ = 0.5 \times (9.5 + 10) \times 1.6 + 10 \times (40 - 1.6) = 399.5 \text{ sec} \]

\[ c = 0.5 \times i \times h_2 = 0.5 \times h_2 \times i^2 = 0.5 \times 2 \times 100 = 100 \]

The average stopped delay

\[ d_1 = \frac{a + b + c}{V \times CL} = 22.9 \text{ sec} \]

Since \( g_2 \) can not dissipate all the vehicles in \( Q_m \), Equation 4-28 is used to compute the over-saturation delay.

\[ i' = Q_m - g_2/h_2 = 24 - 40/2 = 4 \text{ veh} \]

Over-saturation delay is

\[ d_2 = \frac{area(A) + area(B) + area(C) + area(D)}{V \times CL} \]

\[ = \frac{0.5 \times Q_m \times CL}{V \times CL} + \frac{0.5 \times (i' + Q_m) \times g_2}{V \times CL} + \frac{r \times i}{V \times CL} + \frac{0.5 \times i' \times h_2}{V \times CL} \]

\[ = \frac{0.5 \times Q_m \times CL + 0.5 \times (i' + Q_m) \times g_2 + r \times i' + 0.5 \times h_2 \times i^2}{V \times CL} \]

\[ = \frac{0.5 \times 24 \times CL + 0.5 \times (4 + 24) \times 40 + 40 \times 4 + 0.5 \times 2 \times 4^2}{45.6} = 38.89 \text{ sec/veh} \]

Since \( d_3 \) is smaller than cycle length and the volume is greater than the capacity, Equations 4-29 and 4-30 are used to compute the \( d_4 \). In addition, the new value of \( k \) and \( m \) should be computed based on the actual volume which is 45.7 veh per 100 seconds.

The \( k' \) and \( m' \) is 28.2 and 18.3 respectively.
Since, there is no blackout at the loop detector; Equation 3-10 is used to compute the travel time as follows:

\[
Travel \text{–time} = \frac{L_{TD} - QL}{\text{Speed by detector} \times 2} + \frac{L - L_{TD}}{\text{Speed limit}} + d1 + d2 + d4
\]

\[
= \frac{800 - 19 \times 10}{33.25 \times 5280 + 3600} + \frac{1600 - 800}{45 \times 5280 + 3600} + 22.9 + 38.89 + 18.2 = 104.6 \text{sec}
\]

Therefore, the **travel time for time interval 5 is 104.6 sec.**, and the initial queue for the next time interval is 34.

**Travel Time for Time interval 6**

In time interval 6, there is an initial queue of 34 veh, and the average dwelling time is 0.509 which is smaller than 0.6sec/veh. From Table 6-3, the detected volume is 35.33 veh/ln. These 35.33 vehicles are the observed group which represents the travel time at time interval 6. The average detected speed is 23.56 mph.

Volume: 35.33/100*3600=1272vph;

\[
V/C=1272/1080=1.18;
\]

The density is \(Ktd = \text{flow/speed}=1272/23.56.\approx53.97166 \text{ veh/mile;}

From Equation 4-8, \((n-1) \times g \leq \frac{Q_{t-1}}{D_s} \leq n \times g ;\)

Since \[
\frac{Q_{t-1}}{D_s} = \frac{34}{1800 \div 3600} = 72 \text{ sec ,and} \ g=60, \ n=2
\]

From Equation 4-9, the initial delay is

\[
d3=\frac{Q_{t-1}}{D_s} + (n) \times \text{red } \text{time} = \frac{34}{1800 \div 3600} + (2) \times 40 = 148 \text{ sec}
\]
\( g_1 = 8 \text{ sec}, \text{ and } g_2 = 52 \text{ sec}; \)

\[
W_u = \frac{V - C}{k_d - k_q} = -2.37 \text{ mile/hour}
\]

The queuing rate \( QR(\text{veh/h}) \) is:

\[
QR = \frac{dn}{dt} = (V - C - W_d \times k_d) = 320 \text{veh/h}
\]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[
Q_m = QR \times CL = 320 \times \frac{100}{3600} \approx 8 \text{veh/ln}
\]

Then the initial queue for the next time interval is

\[
Q_{t-1} = \max(0, \sum_{m=1}^{i} Q_m) = 8 + 34 = 42 \text{veh/ln}.
\]

Since \( V \) is greater than Capacity, use the capacity as the incoming volume to estimate the uniform stopped delay. Since \( d_3 \) is greater than a cycle length, all vehicles in the observed group are assumed to be in the queue when they dissipate the intersection. Figure 4-18 and its corresponding equations, as shown in Chapter 4, are used to compute the \( d_1 \) in this time interval.

\( h_1 = 100/30 = 3.33 \text{ sec/veh} \)

\( h_2 = 2 \text{ sec/veh} \)

\[
m = C \times CL = 30 \text{veh}
\]

\[
i = m - \frac{g_2}{h_2} = 30 - \frac{52}{2} = 4 \text{veh}
\]

The area of \( A \) is

\[
a = 0.5 \times (i + m) \times g_2 = 0.5 \times (4 + 30) \times 52 = 884 \text{sec} ;
\]

The area of \( B \) and \( C \) are
\[ b = r \times i = 4 \times 40 = 160 \text{ sec}; \]
\[ c = 0.5 \times (i \times h2) \times i = 0.5 \times h2 \times i^2 = 0.5 \times 2 \times 4^2 = 16 \text{ sec} \]

The average stopped delay \[ d1 = \frac{a + b + c}{V \times CL} = \frac{884 + 160 + 16}{35} = 30 \text{ sec/veh} \]

Since, the Qm*h2 is smaller than g2, Equation 4-27 is used to compute the Over-Saturation delay as follows:

\[ d2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} \times \frac{0.5 \times Qm \times CL}{V \times CL} + \frac{0.5 \times Qm \times Qm \times h2}{V \times CL} \]
\[ = \frac{0.5 \times 8 \times 100}{45.6} + \frac{0.5 \times 8 \times 8 \times 2}{45.6} = 13.13 \text{ sec} \]

Since \( d3 \) is greater than cycle length, Equation 4-33 is used to compute the \( d4 \).

\[ d4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d3 - CL = d3 - 0.5 \times CL = 148 - 50 = 98 \text{ sec} \]

Since there is no blackout on the loop detector, Equation 3-10 is used to compute the travel time of the observed group as follows:

\[ \text{Travel-time} = \frac{L_{TD} - QL}{\text{speed by detector} \times 2} + \frac{L - L_{TD}}{\text{Speed limit}} + d1 + d2 + d4 \]
\[ = \frac{800 - 19 \times 34}{23.6 \times 5280 + 3600} + \frac{1600 - 800}{45 \times 5280 + 3600} + 30 + 13.13 + 98 = 157.7 \text{ sec} \]

Therefore, the travel time for time interval 6 is 157.7 sec., and the initial queue for the next time interval is 42 veh.

The queue length is 19*42=798 ft

**Travel Time for Time Interval 7**

In time interval 7, there is an initial queue of 42 veh, and the average dwelling time is larger than 0.6sec/veh which is the critical value for a blackout situation.

Hence, there is a blackout situation and the average incoming group of vehicles is based on the detected volume of the upstream link i-1 in time intervals 6 and 7.
Algorithm 3 in chapter 5 is used to estimate the travel time in this interval. The turning movement is calculated first. The cumulative volume detected by link i-1 for the first 6 intervals is 629 veh and there is no blackout on link i-1 during the 6th time interval. The cumulative volume detected by link i for the first 6 intervals is 580 veh. Each link has 3 lanes. The maximum number of vehicles that can dissipate departing from link i-1 is:

$$\frac{N_{i-1} \times S_{i-1} \times g_{i-1} \times 6 \times \text{time interval}}{CL_{i-1}} = 3 \times 1800 \times \frac{100}{3600} \times 75 \times \frac{6 \times 100}{3600} = 765.$$ 

Since 765 is greater than 629 vehicles, all the 629 vehicles can dissipate through the intersection in the 6 time intervals.

Since there is only 6 time intervals before the blackout situation to obtain data for establishing the turning movement, the percentage of change for turning movement is

$$t\% = \frac{580 - 629}{629} = -7.79\%$$

The volume detected by link i-1 during time interval 6 is 39veh/ln, and 26veh/ln in time interval 7. The average is \((39+26)/2=33\) veh/ln. Based on the pervious volume observations on link i-1, we have determined the cumulative initial queues at its intersection. The calculations are shown below.

Table 6-4 shows the detected volume on link i-1. The capacity of link i-1 is 1350 vph which is equal to 37.5 veh per 100 seconds. Therefore, the queue at the end of time period 6 is approximately \((46.67+47.33+38.33)-37.5\times3=19.83\) veh
Table 6 - 4 Input volume to Link i-1

<table>
<thead>
<tr>
<th>link i-1</th>
<th>Detector count (veh/100 sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period</td>
<td>1</td>
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<td>2</td>
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<td>9</td>
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<tr>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

Hence, \( V_{i-1} + V_q = 33 + 19.85 = 52.85 \) veh/ln/100 secs cycle length which translates to 1902.6 veh/h/ln. It is bigger than the capacity of link i-1 which is 1395veh/hr/ln.

Therefore, the incoming volume for link i is the capacity of link i-1 which is 1395*3600/100*(1-7.79%)=1286veh/h/ln.

Hence, \( V/C = 1286/1080 = 1.19 \);

From Equation 4-8, \((n-1) \times g \leq \frac{Q_{i-1}}{D_s} \leq n \times g \);

Since \( \frac{Q_{i-1}}{D_s} = \frac{42}{1800 \div 3600} = 84 \text{ sec} \), and \( g = 60 \), \( n = 2 \)

From Equation 4-9, the initial delay is

\[
d_3 = \frac{Q_{i-1}}{D_s} + (n) \times \text{red time} = \frac{42}{1800 \div 3600} + (2) \times 40 = 164 \text{ sec}
\]

\( g_1 = 24 \text{ sec} \), and \( g_2 = 36 \text{ sec} \)

Use the capacity as the incoming volume to estimate the uniform stopped delay, because it is less than the incoming volume of the observed group. Since \( d_3 \) is
greater than the cycle length, all vehicles in the observed group are assumed to be in the queue when they dissipate the intersection. Figure 4-18 and its corresponding equations, as shown in Chapter 4, are used to compute the d1 in this time interval.

\[ h_1 = \frac{100}{30} = 3.33 \text{ sec/veh} \]

\[ h_2 = 2 \text{ sec/veh} \]

\[ m = C \times CL = 30 \text{ veh} \]

\[ i = m - \frac{g_2}{h_2} = 30 - \frac{36}{2} = 12 \text{ veh} \]

The area of A is

\[ a = 0.5 \times (i + m) \times g_2 = 0.5 \times (12 + 30) \times 36 = 756 \text{ sec} \]

The area of B and C are

\[ b = r \times i = 12 \times 40 = 480 \text{ sec} \]

\[ c = 0.5 \times (i \times h_2) \times i = 0.5 \times h_2 \times i^2 = 0.5 \times 2 \times 12^2 = 144 \text{ sec} \]

The average stopped delay \( d_1 \)

\[ d_1 = \frac{a + b + c}{V \times CL} = \frac{756 + 480 + 144}{35} = 38.6 \text{ sec/veh} \]

Because of the blackout situation, the shockwave method is not reliable to estimate the queue length. Instead, a base method is used to calculate Qm as 

\[ (V - C) \times CL \]

which is explained in algorithm 3 in Chapter 5.

At the end of time interval 7, the number of vehicles in queue is computed as follows:

\[ Q_{L_{in\_time\_i-1}} + (V - C) \times CL = 42 + (1286-1080) \times 100/3600 = 47 \text{ veh/ln} \]

\[ Q_m = (V - C) \times CL = 5.7 \text{ veh.} \]

Since Qm*h2 is smaller than the g2, the over-saturation delay is computed as follows:

\[ d_2 = \frac{area(B) + area(C)}{V \times CL} = \frac{0.5 \times Q_m \times CL}{V \times CL} + \frac{0.5 \times Q_m \times Q_m \times h_2}{V \times CL} \]

\[ = \frac{0.5 \times 5.7 \times 100}{35.7} + \frac{0.5 \times 5.7 \times 5.7 \times 2}{35.7} = 8.7 \text{ sec} \]
Since \( d3 \) is greater than cycle length, Equation 4-33 is used to compute the \( d4 .. \)

\[
d4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d3 - CL = d3 - 0.5 \times CL = 164 - 50 = 114 \text{ sec}
\]

Since the queue length is longer than the location of loop detector, Equation 3-11 is used to estimate the average travel time as follows:

\[
\text{Travel } - \text{ time} = \frac{L - QL}{\text{Speed } \_\text{limit} \div 2} + d1 + d2 + d4
\]

\[
= \frac{1600 - 912}{45 \times 5280 \div 3600 \div 2} + 38.6 + 8.7 + 114 = 185.6 \text{ sec}
\]

Therefore, the travel time for time interval 7 is 185.6 sec., and the initial queue for the next time interval is 48 veh. The queue length is 19*47=893ft :

**Travel Time for Time Interval 8**

In time interval 8, there is an initial queue of 48 veh, and the average dwelling time is bigger than 0.6sec/veh. Hence, there is a blackout situation during this time interval too. The detected traffic data is not reliable due to the blackout situation. Therefore the incoming group of vehicles is based on the average upstream link volume in time intervals 7 and 8.

The percentage of turning movement is \( t\% = 7.79\% \), which is the same as time interval 7 since the conditions did not change.

The volume detected by link i-1 during time interval 7 is 26 veh/ln and 11 veh/ln in time interval 8. The initial queue for time interval 7 is approximately 8.33 veh. The same procedure as in interval 7 is utilized in determining the initial queue, so we will not repeat all the detailed calculations here.
The incoming volume is \((26+11)/2+8.33)\times(1-7.79\%)\times3600/100=907.2\) (veh/h/ln), which is smaller than the capacity of link i-1.

From Equation 4-8, \((n-1)\times g \leq \frac{Q_{i-1}}{D_s} \leq n \times g\); 

Since \(\frac{Q_{i-1}}{D_s} = \frac{47}{1800 \div 3600} = 94\) sec , and \(g=60, n=2\)

From Equation 4-9, the initial delay is 

\[d_3 = \frac{Q_{i-1}}{D_s} + (n-1)\times \text{red \_ time} = \frac{47}{1800 \div 3600} + (2)\times 40 = 174\) sec

Similar to the calculations in the previous interval, the number of vehicle in queue at the end of time interval 8 is \(Q_{L_{\text{in \_ time \_ i-1}}} + (V - C)\times CL = 47 + (903-1080)*100/3600\) =42 veh/ln

g1=34 sec, and g2=26 sec

Since d3 is greater than the cycle length, all vehicles in observed group are assumed to be in the queue when they start to dissipate the intersection. Figure 4-18 and its corresponding equations are used to estimate the uniform stopped delay.

h2=2 sec/veh

\[m = V \times CL = 25.2\text{veh}\]

\[i = m - \frac{g_2}{h_2} = 12.2\text{veh}\]

The area of A is 

\[a = 0.5\times(i + m)\times g_2 = 0.5\times(12.2 + 25.2)\times 26 = 486.2\text{sec};\]

The area of B and C are 

\[b = r \times i = 13.7\times 40 = 488\text{sec};\]

\[c = 0.5\times(i \times h_2)\times i = 0.5 \times h_2 \times i^2 = 148.8\text{sec}.\]
The average uniform stopped delay 
\[ d_1 = \frac{a + b + c}{V \times CL} = \frac{526 + 550 + 188}{26.7} = 44.5 \text{ sec/veh} \]
\[ d_2 = 0 \text{ sec} \]

Since \( d_3 \) is greater than cycle length, Equation 4-33 is used to compute the \( d_4 \).

\[ d_4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d_3 - CL = d_3 - 0.5 \times CL = 174 - 50 = 124 \text{ sec} \]

Since \( Q_m \) is equal to zero, and since there is a blackout situation, Equation 3-11 is used to estimate the average travel time as follows:

\[ \text{Travel time} = \frac{L - QL}{\text{Speed}} + d_1 + d_2 + d_4 \]
\[ = \frac{1600 - 47 \times 19}{45 \times 5280 / 3600} + 44.5 + 0 + 124 = 190 \text{ sec} \]

Therefore, the **travel time for time interval 8 is 190 sec**, and the initial queue for the next time interval is 42 veh.

**Travel Time for Time interval 9**

In this time interval there is an initial queue of 42 veh, and the average dwelling time is smaller than 0.6 sec/veh. Hence, there is no blackout situation. From Table 6-3, the detected volume is 9.333 veh/ln. These 9.33 vehicles are the observed group which represents the travel time at time interval 9. The average detected speed is 26 mph.

Volume: 9.33/100*3600=336vph;

\( V/C=336/1080=0.31; \) The density is \( Ktd = \text{flow/speed} = 12.919 \text{ veh/mile} \);

From Equation 4-8, \( (n - 1) \times g \leq \frac{Q_{c-1}}{D_s} \leq n \times g \)

Since \( \frac{Q_{c-1}}{D_s} = \frac{42}{1800 \div 3600} = 84 \text{ sec} \), and \( g=60, \ n=2 \)
From Equation 4-9, the initial delay is

$$d_3 = \frac{Q_{r-1}}{D_x} + (n - 1) \times \text{red \_time} = \frac{42}{1800 \div 3600} + (2) \times 40 = 164 \text{sec}$$

$$W_d = \frac{C - V}{k_q - k_{id}} = \frac{1080 - 336}{135 - 12.9} = 6.09 \text{mile \_hour}$$

The queuing rate $QR(\text{veh/h})$ is:

$$QR = \frac{dn}{dt} = (V - C - W_d \times k_d) = (336 - 1080 - 6.09 \times 12.9) = -823 \text{veh \_h}$$

The number of the vehicles in queue which is built during the observed cycle length $t$ will be:

$$Q_m = QR \times CL = -823 \times \frac{100}{3600} \approx -23 \text{veh \_ln}$$

Then the initial queue for the next time interval is

$$Q_{r-1} = \max(0, \sum_{m=1}^{i} Q_m) = 42 - 23 = 19 \text{veh \_ln}$$

The queue length is $19 \times 19 = 361 \text{ft}$:

$g_1 = 24 \text{sec}$, and $g_2 = 36 \text{ sec}$

Since the $d_3$ is greater than the cycle length, all vehicles in observed group are assumed to be in the queue when they start to dissipate the intersection. Figure 4-18 and its corresponding equations are used to estimate the uniform stopped delay.

$h_2 = 2 \text{ sec/veh}$

$$m = V \times CL = 9.33 \text{veh}$$

$$i = m - \frac{g_2}{h_2} < 0$$

Hence, all the vehicles will dissipate the intersection in $g_2$.

The area of $A$ is
\[ a = 0.5 \times m \times m \times h2 = 0.5 \times 9.33 \times 9.33 \times 2 = 87.11 \text{sec} \; ; \]

The area of B and C are

\[ b = c = 0 \; ; \]

The average uniform stopped delay

\[ d1 = \frac{a + b + c}{V \times CL} = \frac{87.11}{9.33} = 9.33 \text{sec/veh} \]

\[ d2 = 0 \text{sec} \; \text{since Qm is smaller than zero} \]

Since \( d3 \) is greater than cycle length, Equation 4-33 is used to compute the \( d4 \).

\[ d4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d3 - CL = d3 - 0.5 \times CL = 164 - 50 = 114 \text{sec} \]

Since there is no blackout situation, Equation 3-11 is used to estimate the travel time as follows:

\[
\text{Travel time} = \frac{L_{TD} - QL}{\text{speed by detector} \times 2} + \frac{L - L_{TD}}{\text{speed limit}} + d1 + d2 + d4
\]

\[ = \frac{800 - 19 \times 43}{26 \times 5280 \div 3600} + \frac{1600 - 800}{45 \times 5280 \div 3600} + 9.33 + 0 + 114 = 135.5 \text{sec} \]

Therefore, the travel time for time interval 9 is **135.5 sec**, and the initial queue for the next time interval is 19 veh.

**Travel Time for Time Interval 10**

In time interval 10, there is an initial queue of 19 veh based on the calculation of the previous time period. And the average dwelling time is smaller than 0.7sec/veh.

Hence, there is no blackout situation. The detected volume is 8.33 veh/ln. These 8.33 veh are the observed group which represents the travel time at time interval 10. The average speed detected by detector is 41.6 mph.

Volume: \( 8.33/100\times3600=300\text{vph} \);
V/C = 300/1080 = 0.2788;

The density is Ktd = flow/speed = 7.2 veh/mile;

From Equation 4-8, \( (n-1) \times g \leq \frac{Q_{n-1}}{D_s} \leq n \times g \);

Since \( \frac{Q_{n-1}}{D_s} = \frac{19}{1800 \div 3600} = 38 \text{ sec} \), and \( g = 60 \), \( n = 1 \)

From Equation 4-9, the initial delay is

\[
D_3 = \frac{Q_{n-1}}{D_s} \times (n) \times \text{red \_time} = \frac{19}{1800 \div 3600} \times (1) \times 40 = 78 \text{ sec}
\]

\[
W_d = \frac{C - V}{k_q - k_{id}} = \frac{1080 - 300}{135 - 7.2} = 6.1 \text{ mile/hour}
\]

The queuing rate QR(veh/h) is:

\[
QR = \frac{dn}{dt} = (V - C - W_d \times k_{id}) = (300 - 1080 - 6.10 \times 7.2) = -824 \text{ veh/h}
\]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[
Q_m = QR \times CL = -824 \times \frac{100}{3600} \approx -23 \text{ veh/ln}
\]

Then the initial queue for the next time interval is

\[
Q_{n-1} = \max(0, \sum_{m=1}^{t} Q_m) = \min(0, 19 - 23) = 0 \text{ veh/ln}
\]

The queue length is 0*19 = 0 ft:

Since the \( d_3 \) is smaller than a cycle length, Figure 4-10 and its relative equations are used to estimate the uniform stopped delay,

\( g_1 = 38 \text{ sec}, g_2 = 22 \text{ sec} \)

\( h_1 = 100/8.33 = 12 \text{ sec/veh} \)

\( h_2 = 2 \text{ sec/veh} \)

\( S_1 = 41.6 \text{ mph}, S_2 = 6.5 \text{ mph} \)
\[
 t = \frac{S1 \times h1 - 19}{S1 - S2} = 13.7; \\
 h3 = \frac{t \times h2}{t - h2} = \frac{13.7 \times 2}{13.7 - 2} = 2.34 \text{ sec/veh}
\]

Since volume of last time interval is smaller than the intersection capacity, Figure 4-20 in Chapter 4 and the relative equations are used to compute the uniform stopped delay in this time interval.

And the \( t4-t3 \) in time interval 9 is zero.

\[
 L = m + Iq - \frac{g1 + g2}{h3} = -2.2 < 0 \\
 k = m + Iq - \frac{g1}{h3} = \frac{40}{12} + 19 - \frac{40}{2.34} = 6.3 \text{ veh}
\]

Since \( L \) is smaller than zero, all vehicles in the observed group will dissipate the intersection in \( g2 \).

The uniform stopped delay for this observed group is

\[
 d1 = \frac{0.5 \times Q_{\text{max}} \times Q_{\text{arrival}}}{Q_{\text{arrival}}} = \frac{0.5 \times k \times (k \times h3)}{8.33} = 5.5 \text{ sec/veh}; \\
 d2=0, \text{ since } V \text{ is smaller than the capacity.}
\]

Since \( d3 \) is smaller than the cycle length and the volume is smaller than the capacity in this time interval, Equation 4-29 and 4-30 are used to computed the \( d4 \) with the same \( k \) and \( m \) values.

\[
 d4 = \frac{0.5 \times r \times m + 0.5 \times (m + k) \times g1}{8.33} = \frac{0.5 \times 40 \times 3.33 + 0.5 \times (3.33 + 6.11) \times 38}{8.33} = 29.53 \text{ sec}
\]

The average travel time is computed as follows:
The travel time on link \( i \) is given by:

\[
Travel\_time = \frac{L_{TD} - QL}{\text{speed \_by \_detector}} \times 2 + \frac{L - L_{TD}}{\text{Speed \_limit}} + d1 + d2 + d4
\]

\[
= \frac{800 - 19 \times 20}{26 \times 5280 \div 3600} + \frac{1600 - 800}{45 \times 5280 \div 3600} + 5.5 + 0 + 29.53 = 54.1\text{sec}
\]

And the initial queue for next time interval is 0 veh.

Figure 6-3 illustrates the variation of the travel time on link \( i \) over the analysis period of 10 time updates. The travel time components are all displayed in this figure, which include the uniform delay, the oversaturation delay, the initial delay, and the travel time on the other part of the link which is not influenced by the intersection.

The update time is 100 seconds and the intersection cycle length is 100 seconds.

The figure shows that the link travel time increases with the increase in volume and is particularly influenced by the size of the initial delay.

Figure 6 - 3 Travel Time Comparison for 100 sec Time Interval Update

**6.3 The Analysis for the 60 sec Time Interval**

The same above calculations are repeated here for a time interval update of 60 secs, which is the normal update period from the detector. The next section deals with the travel time update of 120 secs which is two minutes. This travel time update of 2
minutes may be more appropriate for real time application.

The reader may wish to skip these two sections to avoid the same repetitious calculations and go directly to section 4-5, which describes the bottleneck condition on Link i+1 and to section 4-6 which describes the comparison of results with CORSIM and their justification.

In order to have the same input volume as for the 100 seconds time interval simulation, the CORSIM simulation is separated into 23 time intervals as shown in Table 6-5. However, the maximum number of time interval setting in CORSIM is only 19. Hence, this condition limited our experiment to 8 cycle lengths or 8 time intervals of 100 secs, which is 800 seconds. Chapter 3 has explained how to convert the detector volume to input volume for different cycle lengths. Table 6-5 uses the conversion methodology in Chapter 3 to obtain the input volume in 100secs interval.

Table 6 - 5 Input Volume Table

<table>
<thead>
<tr>
<th>Input volume by user</th>
<th>Converted volume to cycle length</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 sec interval</td>
<td>100 sec interval</td>
</tr>
<tr>
<td>volume(veh/h)</td>
<td>Volume(veh/h)</td>
</tr>
<tr>
<td>1 60</td>
<td>900 0-100</td>
</tr>
<tr>
<td>2 60-100</td>
<td>900 100-200</td>
</tr>
<tr>
<td>3 100-120</td>
<td>2550 200-300</td>
</tr>
<tr>
<td>4 120-180</td>
<td>2550 300-400</td>
</tr>
<tr>
<td>5 180-200</td>
<td>2550 400-500</td>
</tr>
<tr>
<td>6 200-240</td>
<td>3900 500-600</td>
</tr>
<tr>
<td>7 240-300</td>
<td>3900 600-700</td>
</tr>
<tr>
<td>8 300-360</td>
<td>5400 700-800</td>
</tr>
<tr>
<td>9 360-400</td>
<td>5400 800-900</td>
</tr>
<tr>
<td>10 400-420</td>
<td>5100 900-1000</td>
</tr>
<tr>
<td>11 420-480</td>
<td>5100 1000-1100</td>
</tr>
<tr>
<td>12 480-500</td>
<td>5100</td>
</tr>
<tr>
<td>13 500-540</td>
<td>4200</td>
</tr>
<tr>
<td>14 540-600</td>
<td>4200</td>
</tr>
<tr>
<td>15 600-660</td>
<td>3000</td>
</tr>
<tr>
<td>16 660-700</td>
<td>3000</td>
</tr>
<tr>
<td>17 700-720</td>
<td>1200</td>
</tr>
</tbody>
</table>
Data collected from the loop detector in CORSIM is shown in Table 6-1.

Table 6-6 Detector Data (60sec)

<table>
<thead>
<tr>
<th>Time period</th>
<th>Time</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cumulative Vehicles counted</td>
<td>Cumulative Average speed(mph)</td>
<td>Cumulative dwelling time(sec)</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
<td>45</td>
<td>38.8</td>
<td>15.7</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>56</td>
<td>39.9</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>180</td>
<td>110</td>
<td>39.8</td>
<td>37.3</td>
</tr>
<tr>
<td>4</td>
<td>240</td>
<td>160</td>
<td>39.5</td>
<td>52.4</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>210</td>
<td>39.6</td>
<td>69.6</td>
</tr>
<tr>
<td>6</td>
<td>360</td>
<td>287</td>
<td>39.1</td>
<td>93.2</td>
</tr>
<tr>
<td>7</td>
<td>420</td>
<td>336</td>
<td>38.4</td>
<td>109.9</td>
</tr>
<tr>
<td>8</td>
<td>480</td>
<td>431</td>
<td>36.4</td>
<td>147</td>
</tr>
<tr>
<td>9</td>
<td>540</td>
<td>486</td>
<td>34.2</td>
<td>177.3</td>
</tr>
<tr>
<td>10</td>
<td>600</td>
<td>565</td>
<td>30.9</td>
<td>235.3</td>
</tr>
<tr>
<td>11</td>
<td>660</td>
<td>604</td>
<td>29.3</td>
<td>295.3</td>
</tr>
<tr>
<td>12</td>
<td>720</td>
<td>659</td>
<td>27.5</td>
<td>354.6</td>
</tr>
<tr>
<td>13</td>
<td>780</td>
<td>721</td>
<td>25.7</td>
<td>414.6</td>
</tr>
<tr>
<td>14</td>
<td>800</td>
<td>730</td>
<td>25.5</td>
<td>422.6</td>
</tr>
</tbody>
</table>

The number of vehicles at time period \( t \) in Table 6-6 is equal to \( \frac{(A_t) - (A_{t-1})}{3} \)

where 3 represent the number of lanes.

The average speed at time \( t \) in Table 6-5 is calculated using columns A and B in Table 6-2 as follows; \( \frac{A_t \times B_t - A_{t-1} \times B_{t-1}}{A_t - A_{t-1}} \) (mph);  

The average dwelling time is calculated using columns C and A as follows;
\[ \frac{C_t - C_{t-1}}{A_t - A_{t-1}} \text{ (sec/veh)}; \]

The average occupancy at the detector = \((\text{average dwelling time}) \cdot \text{CL}/3600 \cdot 100\%;\)

The data calculated for each time interval using Table 6-6 is shown in Table 6-7.

---

**Table 6 - 7 Data for Each Time Interval (60 sec)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Veh counted</th>
<th>Dwelling time (sec)</th>
<th>Average speed (mph)</th>
<th>Average dwelling time (sec/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>15</td>
<td>5.2</td>
<td>38.8</td>
<td>0.35</td>
</tr>
<tr>
<td>120</td>
<td>3.7</td>
<td>1.1</td>
<td>44.4</td>
<td>0.3</td>
</tr>
<tr>
<td>180</td>
<td>18</td>
<td>6.1</td>
<td>39.7</td>
<td>0.34</td>
</tr>
<tr>
<td>240</td>
<td>16.7</td>
<td>5</td>
<td>38.8</td>
<td>0.3</td>
</tr>
<tr>
<td>300</td>
<td>16.3</td>
<td>5.7</td>
<td>39.9</td>
<td>0.34</td>
</tr>
<tr>
<td>360</td>
<td>25.7</td>
<td>7.9</td>
<td>37.7</td>
<td>0.31</td>
</tr>
<tr>
<td>420</td>
<td>16.3</td>
<td>5.6</td>
<td>34.3</td>
<td>0.34</td>
</tr>
<tr>
<td>480</td>
<td>31.7</td>
<td>12.4</td>
<td>29.3</td>
<td>0.39</td>
</tr>
<tr>
<td>540</td>
<td>18.3</td>
<td>10.1</td>
<td>17</td>
<td>0.55</td>
</tr>
<tr>
<td>600</td>
<td>26.3</td>
<td>19.3</td>
<td>10.6</td>
<td>0.73</td>
</tr>
<tr>
<td>660</td>
<td>13</td>
<td>20</td>
<td>6.1</td>
<td>1.54</td>
</tr>
<tr>
<td>720</td>
<td>18.3</td>
<td>19.8</td>
<td>7.7</td>
<td>1.09</td>
</tr>
<tr>
<td>780</td>
<td>20.7</td>
<td>20</td>
<td>6.6</td>
<td>0.97</td>
</tr>
<tr>
<td>800</td>
<td>3</td>
<td>2.7</td>
<td>9.5</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Since the algorithms are based on the intersection cycle length which is 100 secs, the 60 secs data is transferred to 100 seconds time interval. The results are tabulated in Table 6-8.
Table 6 - 8 Tabulated Result

<table>
<thead>
<tr>
<th>Time period</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Veh count</td>
<td>On time (sec)</td>
<td>Average speed (mph)</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>17.4</td>
<td>6</td>
<td>39.6</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>24.8</td>
<td>8.1</td>
<td>39.7</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>27.8</td>
<td>9.1</td>
<td>39.5</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>36.6</td>
<td>11.6</td>
<td>36.7</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
<td>43.2</td>
<td>17.6</td>
<td>28.2</td>
</tr>
<tr>
<td>6</td>
<td>600</td>
<td>38.6</td>
<td>26.1</td>
<td>12.6</td>
</tr>
<tr>
<td>7</td>
<td>700</td>
<td>25.2</td>
<td>33.2</td>
<td>6.9</td>
</tr>
<tr>
<td>8</td>
<td>800</td>
<td>33.7</td>
<td>33.3</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Equation 3-1 is used to transfer the data of 60 seconds to 100 seconds.

For example, in time period 2, t=2.

\[ 180 \leq 200 \leq 240 \text{ Hence, } n=1, k=3. \]

\[ V_i = \frac{[(n+1) \times 60 - (t-1) \times 100]}{60} \times V_{(n+1)\times60} + \frac{100 \times t - 60 \times k}{60} \times V_{(k+1)\times60} + (k - n - 1) \times V_{k\times60} \]

\[ = \frac{[(1+1) \times 60 - (2-1) \times 100]}{60} \times H_{(1+1)\times60} + \frac{100 \times 2 - 60 \times 3}{60} \times H_{(3+1)\times60} + (3 - 1 - 1) \times H_{3\times60} \]

\[ = \frac{20}{60} \times H_{120} + \frac{20}{60} \times H_{240} + (3 - 2) \times H_{180} \]

\[ = \frac{20}{60} \times 3.667 + \frac{20}{60} \times 16.667 + (3 - 2) \times 18 = 24.77 \text{ veh} \]

**Travel Time for Time Interval 1:**

In the first time interval, there is no initial queue. From Table 6-8 the detected volume is 17.44 veh/ln. These 17.44 vehicles are the observed group whose travel time to traverse link i is to be computed for time interval 1. The average detected speed is 39.75 mph.

Volume: 17.44/100*3600=628vph;

V/C=628/1080=0.58;
The density is $K_{td} = \text{flow/speed} = 15.86\ \text{veh/mile}$;

$h_1 = \frac{100}{17.44} = 5.7\ \text{sec/veh}$

$h_2 = 2\ \text{sec/veh}$

$S_1 = 39.5\ \text{mph},\ S_2 = 6.5\ \text{mph}$

$$t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{39.5 \times 5.7 - 19}{39.5 - 6.5} = 6.28;$$

$$h_3 = \frac{t \times h_2}{t - h_2} = \frac{6.28 \times 2}{6.28 - 2} = 2.93\ \text{sec/veh}$$

From Equation 4-14, the uniform stopped delay for this observed group is

$$d_1 = \frac{0.5 \times Q_{\text{max}} \times Q}{\text{Total arrival}} = \frac{0.5 \times \frac{40}{5.7} \times \left(\frac{40}{5.7} \times 2.93 + 40\right)}{17.44} = 12.09\ \text{sec/veh};$$

The over-saturation delay is zero since volume of the observed group is smaller than the intersection capacity

$d_2 = 0;$

Since there is no initial queue for this incoming group, the initial queue $d_3 = 0\ \text{sec}$.

$$W_d = \frac{C - V}{k_q - k_{sd}} = \frac{1080 - 628}{135 - 15.86} = 3.79\ \text{mile/hour}$$

The queuing rate $QR\ (\text{veh/h})$ is:

$$QR = \frac{dn}{dt} = (V - C - W_d \times k_a) = (628 - 1080 - 3.79 \times 15.86) = -512\ \text{veh/h}$$

The number of the vehicles in queue which is built during the observed cycle length $t$ will be:

$$Q_m = QR \times CL = -512 \times \frac{100}{3600} = -14\ \text{veh}$$

Then the initial queue for the next time interval is $Q_{t-1} = \max(0, \sum_{n=1}^{t} Q_m) = 0$. 
Hence, from Equation 3-9 the travel time for this group is:

\[
Travel - time = \frac{L}{speed \_by \_detector} + d1 + d2 + d4
\]

\[
= \frac{1600}{39.6 \times 5280 \div 3600} + 12.09 + 0 + 0 = 39.7 \text{ sec}
\]

Hence, the travel time for time interval 1 is 39.7 sec. And the initial queue for next time interval is zero.

**Travel Time for Time Interval 2:**

In the second time interval, there is no initial queue based on the previous computation, and the average dwelling time is smaller than 0.6sec/veh. Hence, there is no blackout on the loop detector. From Table 6-8, the detected volume is 24.77 veh/h.

These 24.77 veh is the observed group whose travel time is to be computed for time interval 2. The average detected speed is 39.7 mph.

Volume: \(24.77/100 \times 3600 = 892\) vph;

\(V/C = 892/1080 = 0.825\);

The density is \(Ktd = \text{flow/speed} = 22.44 \text{ veh/mile}\);

\(h1 = 100/24.8 = 4 \text{ sec/veh}\)

\(h2 = 2 \text{ sec/veh}\)

\(S1 = 40 \text{ mph, } S2 = 6.5 \text{ mph}\)

\[t = \frac{S1 \times h1 - 19}{(S1 - S2)} = \frac{40 \times 4 - 19}{40 - 6.5} = 4.25;\]

\[h3 = \frac{t \times h2}{t - h2} = \frac{4.25 \times 2}{4.25 - 2} = 3.77 \text{ sec/veh}\]

From Equation 4-14, the average uniform stopped delay for this observed group is computed as follows:
\[ d_1 = \frac{0.5 \times Q_{\text{max}} \times Q_r}{\text{Total arrival}} = \frac{0.5 \times \frac{40}{4} \times \left(\frac{40}{4} \times 3.77 + 40\right)}{24.8} = 15.5 \text{ sec/veh} \]

The over-saturation delay is zero since volume of the observed group is smaller than the intersection capacity

\[ d_2 = 0; \]

Since there is no initial queue for this incoming group, the initial queue \( d_3 = 0 \text{ sec} \).

\[ W_d = \frac{C - V}{k_q - k_d} = \frac{1080 - 900}{135 - 22.44} = 1.67 \text{ mile/hour} \]

The queuing rate \( QR(\text{veh/h}) \) is:

\[ QR = \frac{\text{dn}}{\text{dt}} = (V - C - W_q \times k_w) = (892 - 1080 - 1.67 \times 22.44) = -225 \text{ veh/h} \]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[ Q_m = QR \times CL \approx -6 \text{ veh/ln} \]

Then the initial queue for the next time interval is \( Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 0 \).

Hence the travel time for this group is:

\[ \text{Travel - time} = \frac{L - QL}{\text{speed by detector}} + d1 + d2 + d4 \]

\[ = \frac{1600 - 0}{39.7 \times 5280 \div 3600} + 15.5 + 0 + 0 = 42.9 \text{ ec} \]

Hence, the travel time for time interval 2 is 48.3 sec. And the initial queue for the next time interval is zero.
Travel Time for Time Interval 3:

In time interval 3, there is no initial queue based on the calculation of the previous time periods, and the average dwelling time is smaller than 0.6 sec/veh. Hence, there is no blackout on the loop detector. From Table 6-8, the detected volume is 27.7 veh /ln. The average detected speed is 39.5 mph.

Volume: $\frac{27.7 \times 100 \times 3600}{1000} = 1008$ vph;

$V/C = \frac{1000}{1080} = 0.925$;

The density is $Ktd = \frac{\text{flow}}{\text{speed}} = 25.32$ veh/mile;

$h1 = \frac{100}{27.77} = 3.6$ sec/veh

$h2 = 2$ sec/veh

$S1 = 39.5$ mph, $S2 = 6.5$ mph

From Equation 4-13;

$$t = \frac{S1 \times h1 - 19}{(S1 - S2)} = \frac{39.5 \times 3.6 - 19}{39.5 - 6.5} = 3.7;$$

$$h3 = \frac{t \times h2}{t - h2} = \frac{3.7 \times 2}{3.7 - 2} = 4.31 \text{ sec/veh}$$

From Equation 4-14, the average uniform stopped delay for this observed group is computed as follows:

$$d1 = \frac{0.5 \times Q_{\text{max}} \times Q_t}{\text{Total } \_ \_ \_ \text{ arrival}} = \frac{0.5 \times 40 \times \left(\frac{40}{3.6} \times 4.31 + 40\right)}{27.8} = 17.57 \text{ sec/veh};$$

And $d2 = 0$ since there $Qm = 0$

Since there is no initial queue for this incoming group, the initial queue $d3 = 0$ sec.
The queuing rate \( QR(\text{veh/h}) \) is:

\[
QR = \frac{dn}{dt} = (V - C - W_u \times k_u) = (1000 - 1080 + 0.844 \times 25.32) = -101 \text{veh/h}
\]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[
Q_m = QR \times CL \approx -3 \text{veh/ln}
\]

Then the initial queue for the next time interval is

\[
Q_{t-1} = \max(0, \sum_{m=i}^t Q_m) = 0 \text{veh/h}.
\]

Hence the travel time for this group is:

\[
Travel - time = \frac{L - QL}{\text{speed by detector}} + d1 + d2 + d4
\]

\[
= \frac{1600 - 0}{39.4 \times 5280 \div 3600} + 17.57 + 0 + 0 = 45.2 \text{sec}
\]

Hence, the **travel time for time interval 3 is 45.2 sec**. And the initial queue for next time interval is 0 veh.

**Travel Time for Time Interval 4**

In time interval 4, there is no initial queue based on the calculation of the previous time periods, and the average dwelling time at the detector is smaller than 0.6sec/veh. Hence, there is no blackout on the loop detector. From Table 6-8, the detected volume is 36.6 veh/ln. These 36.6 veh represent the observed group whose travel time is to be calculated for time interval 4. The average detected speed is 36.7
Volume: $36.6/100 \times 3600 = 1332 \text{ vph}$;

$V/C = 1368/1080 = 1.21$;

The density is $Ktd = \text{flow/speed} = 35.8 \text{ veh/mile}$;

Since the Volume is greater than the capacity, the capacity is used as the incoming volume to estimate the $d1$

$h1 = 100/30 = 3.33 \text{ sec/veh}$

$h2 = 2 \text{ sec/veh}$

$S1 = 36.7 \text{ mph}, S2 = 6.5 \text{ mph}$

$$t = \frac{S1 \times h1 - 19}{(S1 - S2)} = \frac{36.7 \times 3.33 - 19}{36.7 - 6.5} = 3.42;$$

$$h3 = \frac{t \times h2}{t - h2} = \frac{3.42 \times 2}{3.42 - 2} = 4.82 \text{ sec/veh}$$

The uniform stopped delay for this observed group is computed as follows:

$$d1 = \frac{0.5 \times Q_{\text{max}} \times Q_{\text{t}}}{\text{Total arrival}} = \frac{0.5 \times 40 \times (\frac{40}{3.3} \times 4.82 + 40)}{36.5} = 16 \text{ sec/veh;}$$

Since there is no initial queue for this incoming group, the initial queue $d3 = 0 \text{ sec.}$

$$W_u = \frac{V - C}{k_{td} - k_q} = -2.4 \text{ mile/hour}$$

The queuing rate $QR(\text{veh/h})$ is:

$$QR = \frac{\text{dn}}{\text{dt}} = (V - C - W_j \times k_u) = 321 \text{ veh/h}$$

The number of the vehicles in queue which is built during the observed cycle
length \( t \) will be:

\[
Q_m = QR \times CL \approx 9\text{veh/ln}
\]

Then the initial queue for the next time interval is

\[
Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 9\text{veh/ln}.
\]

The queue length is \( 9 \times 19 = 171 \text{ft} \):

Since the \( Q_m \) is 9 veh, the over-saturation delay is computed as follows:

\[
d_2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} + \frac{r \times Q_m}{V \times CL} + \frac{0.5 \times Q_m \times Q_m \times h_2}{V \times CL}
\]

\[
= 24.37 \text{sec/veh}
\]

Travel time is

\[
= \frac{L_{TD} - QL}{\text{speed by detector} \times 2} + \frac{L - L_{TD}}{\text{Speed limit}} + d_1 + d_2 + d_4
\]

\[
= \frac{800 - 19 \times 9}{36.7 \times 5280 \div 3600} + \frac{1600 - 800}{45 \times 5280 \div 3600} + 16 + 24.37 + 0 = 67.3 \text{sec}
\]

Hence, the travel time for time \textbf{interval 4 is 67.3 sec}. And the initial queue for next time interval is 9 veh.

**Travel Time for Time Interval 5**

In the time interval 5, there is an initial queue based on the calculation of the previous time period. And the average dwelling time is 0.41sec/veh which is smaller than 0.6sec/veh. Hence, there is no blackout on the loop detector. The detected volume is 43.22 veh/ln. And the average detected speed is 28.2 mph.

Volume: \( 43.22/100 \times 3600 = 1556 \text{vph} \);

\( V/C = 1556/1080 = 1.44 \);

The density is \( Ktd = \text{flow/speed} = 55.16 \text{veh/mile} \);

From Equation 4-8, \( (n - 1) \times g \leq \frac{Q_{t-1}}{D_s} \leq n \times g \);
Since \( \frac{O^{-1}}{D_s} = \frac{9}{1800 \div 3600} = 18 \text{ sec} \), and \( g = 60, n = 1 \)

From Equation 4-9, the initial delay is

\[
d_3 = \frac{O^{-1}}{D_s} + (n) \times \text{red \_ time} = \frac{9}{1800 \div 3600} + (1) \times 40 = 58 \text{ sec}
\]

\( g_1 = 18 \text{ sec}, \text{ and } g_2 = 42 \text{ sec} \)

Since, \( V \) is greater than \( C \), use the capacity as the input volume to estimate the uniform stopped delay \( d_1 \).

\( h_1 = \frac{100}{30} = 3.33 \text{ sec/veh} \)

\( h_2 = 2 \text{ sec/veh} \)

\( S_1 = 28.2 \text{ mph}, S_2 = 6.5 \text{ mph} \)

\[
t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{28.2 \times 3.33 - 19}{28.2 - 6.5} = 3.45 \;
\]

\[
h_3 = \frac{t \times h_2}{t - h_2} = \frac{3.45 \times 2}{3.45 - 2} = 4.74 \text{ sec/veh}
\]

\[
m = \frac{r}{h_1} = \frac{40}{3.33} = 12 \text{ veh}
\]

\[
k = m + lq = \frac{g_1}{h_3} = 12 + 9 - \frac{20}{4.74} = 17.2
\]

\[
L = m + lq = \frac{g_1 + g_2}{h_3} = 12 + 9 - \frac{60}{4.74} = 8.36
\]

\( i = 9 \)

\[
t_4 - t_3 = (i - L) \times h_1 = (9 - 8.36) \times 3.33 = 2.13
\]

\[
a = 0.5 \times (k + L) \times g_2 = 0.5 \times (17.2 + 8.36) \times 40 = 537 \text{ sec}
\]

\[
b = 0.5 \times (L + i) \times (t_4 - t_3) + i \times (\text{red} - (t_4 - t_3))
\]

\[
= 0.5 \times (8.36 + 9) \times 2.13 + 9 \times (40 - 2.13) = 359.3 \text{ sec}
\]

[
= 0.5 \times i \times i \times h_2 = 0.5 \times h_2 \times i^2 = 0.5 \times 2 \times 9 \times 9 = 81
\]

The average uniform stopped delay
\[ d_1 = \frac{a + b + c}{V \times CL} = 22.6 \text{ sec} \]

\[ W_u = \frac{V - C}{k_{id} - k_q} = -6 \text{ mile/hour} \]

The queuing rate \( QR(\text{veh/h}) \) is:

\[ QR = \frac{dn}{dt} = (V - C - W_u \times k_q) = 804.9 \text{ veh/h} \]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[ Q_m = QR \times CL \approx 22 \text{ veh/ln} \]

Then the initial queue for the next time interval is

\[ Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 9 + 22 = 31 \text{ veh/ln} \]

The queue length is \( 19 \times 31 = 589 \text{ ft} \):

Since the \( g_2 \) cannot dissipate all vehicles in \( Q_m \),

\[ i' = Q_m - g_2/h_2 = 22 - 42/2 = 1 \text{ veh} \]

Over-saturation delay is computed as follows:

\[ d_2 = \frac{\text{area}(A) + \text{area}(B) + \text{area}(C) + \text{area}(D)}{V \times CL} \]

\[ = \frac{0.5 \times Q_m \times CL + 0.5 \times (i' + Q_m) \times g^2 + r \times i + 0.5 \times i' \times h_2}{V \times CL} \]

\[ = \frac{0.5 \times 24 \times CL + 0.5 \times (1 + 22) \times 40 + 40 \times 1 + 0.5 \times 2 \times 1^2}{43.2} = 37.6 \text{ sec/veh} \]

Since \( d_3 \) is smaller than cycle length and the volume is greater than the capacity Equation 4-29 and 4-30 are used to compute the \( d_4 \). In addition, the new value of \( k \) and \( m \) should be computed based on the actual volume which is 43.2 veh
per 100 seconds.

The k’ and m’ is 25.7 and 17.3 respectively.

\[
d_4 = \frac{0.5 \times r \times m' + 0.5 \times (m' + k') \times g_1}{Total \_vehicle \_in \_the \_Observed \_Group} \\
= \frac{0.5 \times 40 \times 17.3 + 0.5 \times (25.7 + 17.3) \times 20}{43.2} = 17 \text{ sec}
\]

\[
Travel \text{- time} = \frac{L_{TD} - QL}{speed \_by \_detector \times 2} + \frac{L - L_{TD}}{Speed \_limit} + d_1 + d_2 + d_4 \\
= \frac{800 - 19 \times 9}{28.2 \times 5280 \div 3600} + \frac{1600 - 800}{45 \times 5280 \div 3600} + 22.6 + 37.6 + 17 = 104.5 \text{ sec}
\]

Hence, the travel time for time interval 5 is 104.5 sec. And the initial queue for next time interval is 31 veh.

**Travel Time for Time Interval 6**

In time interval 6, there is an initial queue of 31 vehicles. And the average dwelling time 0.68 is greater than 0.6sec/veh. Hence, it is the critical value for a blackout situation. Hence, there is a blackout situation and the average incoming group of vehicles is based on the detected volume of the upstream link i-1 in time intervals 5 and 6. Algorithm 3 in chapter 5 is used to estimate the travel time in this interval.

The turning movement is calculated first. As stated in the Chapter 3, the closest acceptable time interval here is time interval 5 which is 300 seconds away from the beginning. The cumulative volume detected by link i-1 from 1-300 seconds is 224 vehicles, and 210 on link i. Thus t\%=\frac{(210-224)}{224}=-0.0625=-6.25\%

The average volume of link i-1 in time interval 5 and 6 is 43*3600/100=1548vph
Since the capacity of link i-1 is only 1395vph, the incoming volume in time interval 6 on link i is 1395*(1-6.25%)=1307vph

V/C=1307/1080=1.21;

From Equation 4-8, \((n-1) \times g \leq \frac{Q_{i-1}}{D_s} \leq n \times g\);

Since \(\frac{Q_{i-1}}{D_s} = \frac{31}{1800 \div 3600} = 62\) sec, and \(g=60, n=2\)

From Equation 4-9, the initial delay is

\[d_3 = \frac{Q_{i-1}}{D_s} + (n) \times red\_time = \frac{31}{1800 \div 3600} + (2) \times 40 = 142\) sec

The number of the vehicles in queue which is built during the observed cycle length \(t\) will be:

\[QL_{in\_time\_i-1} + (V - C) \times CL = 31 + (1307-1080) \times 100/3600 = 37\) veh/ln

The queue length is 19*37=703 ft:

\(g1=2\) sec, and \(g2=58\) sec

Use the capacity as the incoming volume to estimate the uniform stopped delay, because it is less than the incoming volume of the observed group. Since \(d_3\) is greater than the cycle length, all vehicles in the observed group are assumed to be in the queue when they dissipate the intersection. Figure 4-18 and its corresponding equations, as shown in Chapter 4, are used to compute the \(d_1\) in this time interval.

\(h1=100/30=3.33\) sec/veh

\(h2=2\) sec/veh

\[m = C \times CL = 30\) veh\]
\[ i = \frac{m - \frac{g^2}{h^2}}{2} = \frac{30 - \frac{58}{2}}{2} = 1 \text{veh} \]

The area of A is

\[ a = 0.5 \times (i + m) \times g^2 = 0.5 \times (1 + 30) \times 58 = 899 \text{sec} ; \]

The area of B and C are

\[ b = r \times i = 1 \times 40 = 40 \text{sec} ; \]

\[ c = 0.5 \times (i \times h^2) \times i = 0.5 \times h^2 \times i^2 = 0.5 \times 2 \times 1^2 = 1 \text{sec} \]

The average stopped delay is computed as follows:

\[ d_1 = \frac{a + b + c}{V \times CL} = \frac{899 + 40 + 1}{36.3} = 25.9 \text{sec/veh} \]

The over-saturation delay is computed as follows:

\[ d_2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} = \frac{0.5 \times Q_m \times CL + 0.5 \times Q_m \times Q_m \times h^2}{V \times CL} \]

\[ = \frac{0.5 \times 6 \times 100}{36.3} + \frac{0.5 \times 6 \times 6 \times 2}{36.3} = 9.2 \text{sec} \]

Since \( d_3 \) is greater than cycle length in this time interval, Equation 4-33 is used to compute the \( d_4 \).

\[ d_4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d_3 - CL = d_3 - 0.5 \times CL = 142 - 50 = 92 \text{sec} \]

\[ \text{Travel-time} = \frac{L - QL}{\text{Speed}_{\text{limit}}} + d_1 + d_2 + d_4 \]

\[ = \frac{1600 - 31 \times 19}{45 \times 5280 \div 3600} + 25.9 + 9.2 + 92 = 157.7 \text{sec} \]

Therefore, the travel time for time interval 6 is 157.7 sec., and the initial queue for the next time interval is 37 veh.

**Travel Time for Time Interval 7**

In time interval 7, there is an initial queue of 37 veh, and the average dwelling
time is bigger than 0.6sec/veh. Hence, there is a blackout situation during this time interval too. The detected traffic data is not reliable due to the blackout situation. Therefore the incoming group of vehicles is based on the average upstream link volume in time intervals 6 and 7.

The detected volume on link i-1 in time interval 6 is 39veh/ln, and 26veh/ln in the time interval 7. The average is \((39.5+25.3)/2=33\) veh/ln. Based on the pervious observation on link i-1, and the initial queue on link i-1 in time period 6 is approximately 19.8 veh which is computed earlier in 100 seconds update. Hence, \(V_{i-1} + V_q = 33+19.8=52.8\) veh/ln = 1900 veh/h/ln. It is bigger than the capacity of link i-1. Hence, the incoming volume for link i is the capacity of link i times turning factor which is \(1395*(1-6.25%)=1307\)veh/h/ln.

\(V/C=1307/1080=1.2;\)

From Equation 4-8, \((n-1)\times g \leq \frac{Q_{t-1}}{D_s} \leq n \times g;\)

Since \(\frac{Q_{t-1}}{D_s} = \frac{37}{1800 \div 3600} = 74\) sec, and \(g=60, n=2\)

From Equation 4-9, the initial delay is

\[d_3=\frac{Q_{t-1}}{D_s} + (n) \times \text{red time} = \frac{37}{1800 \div 3600} + (2) \times 40 = 154\text{ sec}\]

At the end of time interval 7, the number of vehicle in queue is \(Q_{L_{in\_time\_i-1}} + (V - C) \times CL = 37+(1307-1080)*100/3600 =43\) veh/ln

Then the initial queue for the next time interval is

The queue length is \(19*43=817\) ft:

\(g_1=14\text{ sec}, \text{ and } g_2=46\text{ sec}\)
Use the capacity as the incoming volume to estimate the uniform stopped delay, because it is less than the incoming volume of the observed group. Since $d_3$ is greater than the cycle length, all vehicles in the observed group are assumed to be in the queue when they dissipate the intersection. Figure 4-18 and its corresponding equations, as shown in Chapter 4, are used to compute the $d_1$ in this time interval.

$h_1 = \frac{100}{30} = 3.33 \text{ sec/veh}$

$h_2 = 2 \text{ sec/veh}$

$m = C \times CL = 30 \text{ veh}$

$i = m - \frac{g_2}{h_2} = 30 - \frac{46}{2} = 7 \text{ veh}$

The area of A is

$a = 0.5 \times (i + m) \times g_2 = 0.5 \times (7 + 30) \times 46 = 851 \text{ sec}$;

The area of B and C are

$b = r \times i = 7 \times 40 = 280 \text{ sec};$

$c = 0.5 \times (i \times h_2) \times i = 0.5 \times h_2 \times i^2 = 0.5 \times 2 \times 7^2 = 49 \text{ sec}$

The average uniform stopped delay

$d_1 = \frac{a + b + c}{V \times CL} = \frac{851 + 280 + 49}{36.8} = 32.4 \text{ sec/veh}$

Over-saturation delay is

$$d_2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} = \frac{0.5 \times Q_m \times CL}{V \times CL} + \frac{0.5 \times Q_m \times Q_m \times h_2}{V \times CL}$$

$$= \frac{0.5 \times 6 \times 100}{35.7} + \frac{0.5 \times 6 \times 6 \times 2}{35.7} = 9.3 \text{ sec}$$

Since $d_3$ is greater than cycle length, Equation 4-33 is used to compute the $d_4$. 

133
\[ d_4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d_3 = CL = d_3 - 0.5 \times CL = 154 - 50 = 104 \text{ sec} \]

Since the queue length is longer than the location of loop detector, the travel time is computed as follows:

\[
\text{Travel } \text{ time} = \frac{L - QL}{\text{Speed } \text{ limit}} + d_1 + d_2 + d_4
\]

\[
= \frac{1600 - 37}{45 \times 5280 \div 3600 \div 2} + 32.4 + 9.3 + 154 = 173 \text{ sec}
\]

Therefore, the travel time for time interval 7 is 173 sec and the initial queue for next time interval is 43 veh.

**Travel Time for Time Interval 8**

In time interval 8, there is an initial queue of 43 veh, and the average dwelling time is bigger than 0.6 sec/veh. Hence, there is a blackout situation during this time interval too. The detected traffic data is not reliable due to the blackout situation. Therefore the incoming group of vehicles is based on the average upstream link volume in time intervals 7 and 8.

The turning movement: the turning movement is -6.25%.

The detected volume on link i-1 during time interval 7 is 25.33 veh/ln and 12.22 veh/ln in time interval 8. The initial queue for time interval 7 is approximately 8.33 which is computed earlier. Hence, the incoming volume is

\[
((25.33 + 12.22)/2 + 8.33) \times 3600/100 \times (1 - 6.25\%) = 922.4 \text{ (veh/h/ln)}
\]

It is smaller than the capacity of link i-1.

Therefore, 922.4 v/h/ln is the incoming volume.
From Equation 4-18, \((n-1) \times g \leq \frac{Q_{r-i}}{D_s} \leq n \times g\);

Since \(\frac{Q_{r-i}}{D_s} = \frac{43}{1800 \div 3600} = 96\text{ sec}\), and \(g=60, n=2\)

From Equation 4-9, the initial delay is

\[d_3 = \frac{Q_{r-i}}{D_s} + (n) \times \text{red time} = \frac{43}{1800 \div 3600} + (2) \times 40 = 166\text{ sec}\]

Since the Ktd in this time interval is not reliable due to the blackout, the shockwave method is not good in this situation to estimate the queue length. A base method is used instead of it.

At the end of time interval 7, the number of vehicle in queue is

\[QL_{in\_time\_i-1} + (V - C) \times CL = 43 + (922 - 1080) \times 100/3600 = 38\text{ veh/ln}\]

\(g_1=26\text{ sec}, \text{ and } g_2=34\text{ sec}\)

Since the \(d_3\) is greater than a cycle length, all vehicles in observed group are in the queue when dissipating the intersection is assumed.

\(h_2=2\text{ sec/veh}\)

\[m = V \times CL = 25.6\text{ veh}\]

\[i = m - \frac{g_2}{h_2} = 8.62\text{ veh}\]

The area of A is

\[a = 0.5 \times (i + m) \times g_2 = 0.5 \times (8.62 + 25.6) \times 34 = 582.14\text{ sec}\;\]

The area of B and C are

\[b = r \times i = 8.62 \times 40 = 344.9\text{ sec}\;\]

\[c = 0.5 \times (i \times h_2) \times i = 0.5 \times h_2 \times i^2 = 74.3\text{ sec}\]
The average uniform stopped delay  

\[
d_{1} = \frac{a + b + c}{V \times CL} = 39.1 \text{sec/veh}
\]

\[
d_{2} = 0 \text{sec} \quad \text{since Qm is smaller than zero}
\]

Since \(d_{3}\) is greater than cycle length, Equation 4-33 is used to compute the \(d_{4}\).

\[
d_{4} = \frac{0.5 \times V \times CL^{2}}{V \times CL} + d_{3} - CL = d_{3} - 0.5 \times CL = 166 - 50 = 116 \text{sec}
\]

\[
\text{Travel - time} = \frac{L - QL}{\text{Speed limit}/2} + d_{1} + d_{2} + d_{4}
\]

\[
= \frac{1600 - 43 \times 19}{45 \times 5280 / 3600 / 2} + 39.1 + 0 + 166 = 178.8 \text{sec}.
\]

Figure 6-5 provides the variation of travel time over the 8 time intervals of 100 secs, with detector data obtained at 60 secs updates. The same results as in case 1 of 100 secs detector input data are shown, except that the 8 simulated periods were not enough to allow the volume to decrease and consequently get rid of the built up queues.
6.4 The analysis for 120 second time interval.

In this experiment, the travel time update is 120s while the cycle length is 100secs. Similar to the Section 4-3 the CORSIM simulation is separated into 19 time intervals instead of 10 time intervals. It is shown in Table 6-9.

Table 6 - 9 Input Volume Table

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Volume (vph)</th>
<th>Time (sec)</th>
<th>Volume (vph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>0-100</td>
<td>900</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>100-200</td>
<td>2550</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>200-300</td>
<td>3900</td>
</tr>
<tr>
<td>4</td>
<td>240</td>
<td>300-400</td>
<td>5400</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>400-500</td>
<td>5100</td>
</tr>
<tr>
<td>6</td>
<td>360</td>
<td>500-600</td>
<td>4200</td>
</tr>
<tr>
<td>7</td>
<td>400</td>
<td>600-700</td>
<td>3000</td>
</tr>
<tr>
<td>8</td>
<td>480</td>
<td>700-800</td>
<td>1200</td>
</tr>
<tr>
<td>9</td>
<td>500</td>
<td>800-900</td>
<td>900</td>
</tr>
<tr>
<td>10</td>
<td>600</td>
<td>900-1000</td>
<td>600</td>
</tr>
<tr>
<td>11</td>
<td>700</td>
<td>1000-1100</td>
<td>600</td>
</tr>
<tr>
<td>12</td>
<td>720</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>800</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>840</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>900</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>960</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1000</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>1080</td>
<td>600</td>
<td></td>
</tr>
</tbody>
</table>

The data collected from the loop detector in CORSIM is shown in Table 6-10.

Table 6 - 10 Loop Detector Cumulative Data

<table>
<thead>
<tr>
<th>Time period</th>
<th>Time</th>
<th>Veh counted</th>
<th>Cumulative On time (sec)</th>
<th>Cumulative Average speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
<td>57</td>
<td>19.3</td>
<td>39.2</td>
</tr>
<tr>
<td>2</td>
<td>240</td>
<td>160</td>
<td>54</td>
<td>39.3</td>
</tr>
<tr>
<td>3</td>
<td>360</td>
<td>291</td>
<td>95.3</td>
<td>39.3</td>
</tr>
<tr>
<td>4</td>
<td>480</td>
<td>433</td>
<td>147.9</td>
<td>36.7</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>568</td>
<td>238.5</td>
<td>31.1</td>
</tr>
<tr>
<td>6</td>
<td>720</td>
<td>661</td>
<td>358.5</td>
<td>27.7</td>
</tr>
<tr>
<td>7</td>
<td>840</td>
<td>752</td>
<td>439.5</td>
<td>25.6</td>
</tr>
<tr>
<td>8</td>
<td>960</td>
<td>783</td>
<td>450.1</td>
<td>26.2</td>
</tr>
<tr>
<td>9</td>
<td>1080</td>
<td>805</td>
<td>457.3</td>
<td>26.7</td>
</tr>
</tbody>
</table>
The data calculated for each time interval using Table 6-10 is shown in Table 6-11:

<table>
<thead>
<tr>
<th>Time period</th>
<th>Time</th>
<th>Veh counted</th>
<th>On time (sec/120 sec)</th>
<th>Occupancy</th>
<th>Average speed (mph)</th>
<th>Average dwelling time (sec/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
<td>19</td>
<td>6.4</td>
<td>10.7</td>
<td>39.2</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>240</td>
<td>34.3</td>
<td>11.6</td>
<td>19.3</td>
<td>39.4</td>
<td>0.34</td>
</tr>
<tr>
<td>3</td>
<td>360</td>
<td>43.7</td>
<td>13.8</td>
<td>22.9</td>
<td>39.3</td>
<td>0.32</td>
</tr>
<tr>
<td>4</td>
<td>480</td>
<td>47.3</td>
<td>17.5</td>
<td>29.2</td>
<td>31.4</td>
<td>0.37</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>45</td>
<td>30.2</td>
<td>50.3</td>
<td>13.1</td>
<td>0.67</td>
</tr>
<tr>
<td>6</td>
<td>720</td>
<td>31</td>
<td>40</td>
<td>66.7</td>
<td>6.9</td>
<td>1.29</td>
</tr>
<tr>
<td>7</td>
<td>840</td>
<td>30.3</td>
<td>27</td>
<td>45</td>
<td>10.3</td>
<td>0.89</td>
</tr>
<tr>
<td>8</td>
<td>960</td>
<td>10.3</td>
<td>3.5</td>
<td>5.9</td>
<td>40.8</td>
<td>0.34</td>
</tr>
<tr>
<td>9</td>
<td>1080</td>
<td>7.3</td>
<td>2.4</td>
<td>4</td>
<td>44.5</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Since the algorithms are based on the intersection cycle length which is 100 secs, the 120 secs data is transferred to 100 seconds time interval. The results are tabulated in Table 6-12. And Equation 3-2 and 1-3 are used.

For example, for the 100-200 seconds, it composes of the traffic data in the last 20 second from the data of 0-120, and 80 seconds traffic data from 120-240.

Hence:

\[
V_2 = 19 \times \frac{20}{120} + 34.3 \times \frac{80}{120} = 26.05 \text{veh}
\]

On time for time interval 1 is \(6.43 \times \frac{20}{120} + 11.5 \times \frac{80}{120} = 8.78 \text{sec}\);

The average speed is \(\frac{39.2 \times 19 \times \frac{20}{120} + 39.35 \times 34.33 \times \frac{80}{120}}{26.05} = 39.33 (mph)\)

Average dwelling time is \(8.78/26.05 = 0.337 \text{sec/veh}\)

The result is shown in Table 6-12.
Table 6 - 12 Data Transfer From Loop Detector

<table>
<thead>
<tr>
<th>Time period</th>
<th>Time</th>
<th>Veh counted</th>
<th>On time (sec/120sec)</th>
<th>Occupancy</th>
<th>Average speed (mph)</th>
<th>Average dwelling time (sec/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>15.8</td>
<td>5.4</td>
<td>5.4</td>
<td>39.2</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>26.1</td>
<td>8.8</td>
<td>8.8</td>
<td>39.3</td>
<td>0.34</td>
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<td>300</td>
<td>33.3</td>
<td>10.7</td>
<td>10.7</td>
<td>39.3</td>
<td>0.32</td>
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<td>12.7</td>
<td>12.7</td>
<td>36</td>
<td>0.34</td>
</tr>
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<td>500</td>
<td>39.1</td>
<td>16.7</td>
<td>16.7</td>
<td>27.9</td>
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<td>600</td>
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<td>25.2</td>
<td>25.2</td>
<td>13.1</td>
<td>0.67</td>
</tr>
<tr>
<td>7</td>
<td>700</td>
<td>25.8</td>
<td>33.3</td>
<td>33.3</td>
<td>6.9</td>
<td>1.29</td>
</tr>
<tr>
<td>8</td>
<td>800</td>
<td>25.4</td>
<td>24.7</td>
<td>24.7</td>
<td>9.7</td>
<td>0.97</td>
</tr>
<tr>
<td>9</td>
<td>900</td>
<td>15.3</td>
<td>10.8</td>
<td>10.8</td>
<td>20.6</td>
<td>0.70</td>
</tr>
<tr>
<td>10</td>
<td>1000</td>
<td>7.6</td>
<td>2.6</td>
<td>2.6</td>
<td>42</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Travel Time for Time Interval 1:

In the first time interval, there is no initial queue. From Table 6-12 the detected volume is 15.8 veh/ ln. These 15.8 veh are the observed group whose travel time to traverse link i is to be computed for time interval 1. The average speed detected by detector is 39.2mph.

Volume: 15.83/100*3600=576vph;

V/C=570/1080=0.53;

The density is Ktd =flow/speed=14.5 veh/mile;

Since there is no initial queue for this incoming group, the initial queue d3=0sec.

\[ W_d = \frac{C - V}{k_q - k_{id}} = \frac{1080 - 570}{135 - 14.5} = 4.23 \text{mile/hour} \]

The queuing rate QR(veh/h) is:
The number of the vehicles in queue which is built during the observed cycle length $t$ will be:

$$Q_m = QR \times CL = -16 \text{veh}$$

Then the initial queue for the next time interval is $Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 0$.

$h_1 = \frac{100}{15.8} = 6.3 \text{ sec/veh}$

$h_2 = 2 \text{ sec/veh}$

$S_1 = 39.2 \text{ mph}, S_2 = 6.5 \text{ mph}$

$$t = \frac{S_1 \times h_1 - 19}{S_1 - S_2} = \frac{39.2 \times 6.3 - 19}{39.2 - 6.5} = 7;$$

$$h_3 = \frac{t \times h_2}{t - h_2} = \frac{7 \times 2}{7 - 2} = 2.8 \text{ sec/veh}$$

From Equation 4-14, the average uniform stopped delay for this observed group is computed as follows:

$$d_1 = 0.5 \times \frac{Q_{\text{max}} \times Q_{\text{arrival}}}{\text{Total }} = 0.5 \times \frac{\frac{40}{7} \times \left(\frac{40}{7} \times 2.8 + 40\right)}{15.9} = 11.5 \text{ sec/veh};$$

Since the over-saturation delay is zero and volume of observed group is smaller than the intersection capacity

$$d_2 = 0;$$

Hence the travel time for this group is computed as follows:

$$Travel - time = \frac{L}{speed \_by \_detector} + d_1 + d_2 + d_4$$

$$= \frac{1600}{39.2 \times 5280 \div 3600} + 11.5 + 0 + 0 = 39.37 \text{ sec}$$

Therefore, the travel time for time interval 1 is 39.37 sec and the initial queue
for next time interval is zero.

**Travel Time for Time Interval 2:**

In the second time interval, there is no initial queue based on the previous computation, and the average dwelling time is smaller than 0.6sec/veh. Hence, there is no blackout on the loop detector. From Table 6-12, the detected volume is 26.05 veh/ln. These 26.05 veh is the observed group whose travel time is to be computed for time interval 2. The average speed detected by detector is 39.33mph.

Volume: 26.05/100*3600=938vph;

V/C=938/1080=0.87;

The density is Ktd =flow/speed=23.84 veh/mile;

h1=100/26.1=3.83 sec/veh

h2=2 sec/veh

S1=39.3mph, S2=6.5 mph

From Equation 4-13;

\[
\begin{align*}
t &= \frac{S1 \times h1 - 19}{(S1 - S2)} = \frac{39.3 \times 3.83 - 19}{3.83 - 6.5} = 4; \\
h3 &= \frac{t \times h2}{t - h2} = \frac{4 \times 2}{4 - 2} = 3.98 \text{ sec/veh}
\end{align*}
\]

From Equation 4-14, the average uniform stopped delay for this observed group is computed as follows:

\[
\begin{align*}
d1 &= \frac{0.5 \times Q_{\text{max}} \times Q_{t}}{\text{Total _arrival}} = \frac{0.5 \times 40}{3.83} \times \left( \frac{40}{3.83} \times 3.98 + 40 \right) \times 26 = 16.3 \text{ sec/veh}; \\
\text{The over-saturation delay is zero since } V \text{ is smaller than Capacity}
\end{align*}
\]

\[
d2 = 0;
\]
Since there is no initial queue for this incoming group, the initial queue
d3=0sec.

\[ W_d = \frac{C - V}{k_q - k_{ld}} = \frac{1080 - 938}{135 - 23.84} = 1.277 \text{ mile/hour} \]

The queuing rate \( QR(\text{veh/h}) \) is:

\[ QR = \frac{dn}{dt} = (V - C - W_q \times k_d) = -172 \text{ veh/h} \]

The number of the vehicles in queue which is built during the observed cycle
length \( t \) will be:

\[ Q_m = QR \times CL \approx -5 \text{ veh/ln} \]

Then the initial queue for the next time interval is \( Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 0 \).

Hence the travel time for this group is computed as follows:

\[ \text{Travel - time} = \frac{L - QL}{\text{speed by detector}} + d1 + d2 + d4 \]
\[ = \frac{1600 - 0}{39.3 \times 5280 \div 3600} + 16.3 + 0 + 0 = 44 \text{ sec} \]

Therefore, the travel time for time interval 2 is 44 sec. And the initial queue
for the next time interval is zero.

**Travel Time for Time Interval 3:**

In third time interval, there is no initial queue based on the calculation of the
previous time period 2, and the average dwelling time is smaller than 0.6sec/veh.

Hence, there is no blackout on the loop detector. From Table 6-12, the detected
volume is 33.27 veh/ln. The average speed detected by detector is 39.31 mph.

Volume: 33.27/100*3600=1198vph;
\[ V/C = \frac{1198}{1080} = 1.11; \]

The density is \( K_{td} = \text{flow/speed} = 30.47 \text{ veh/mile}; \)

Since, \( V \) is greater than \( C \), use the capacity as the input volume to estimate the uniform stopped delay \( d_1 \):

\[ h_1 = \frac{100}{30} = 3.33 \text{ sec/veh} \]

\[ h_2 = 2 \text{ sec/veh} \]

\( S_1 = 39.3 \text{ mph}, S_2 = 6.5 \text{ mph} \)

\[ t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{39.3 \times 3.33 - 19}{39.3 - 6.5} = 3.42; \]

\[ h_3 = \frac{t \times h_2}{t - h_2} = \frac{3.42 \times 2}{3.42 - 2} = 4.82 \text{ sec/veh} \]

The uniform stopped delay for this observed group is computed as follows

\[ d_1 = \frac{0.5 \times Q_{\max} \times Q_t}{Total \_arrival} = \frac{0.5 \times 40 \times \left( \frac{40}{3.3} \times 4.82 + 40 \right)}{33} = 17.65 \text{ sec/veh}; \]

Since there is no initial queue for this incoming group, the initial queue \( d_3 = 0 \text{ sec.} \)

\[ W_u = \frac{V - C}{k_{rd} - k_q} = -1.38 \text{ mile/hour} \]

The queuing rate \( QR(\text{veh/h}) \) is:

\[ QR = \frac{dn}{dt} = (V - C - W_u \times k_u) = 152 \text{ veh/h} \]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[ Q_m = QR \times CL \approx 4 \text{ veh/ln} \]

Then the initial queue for the next time interval is
\[ Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 4 \text{veh/h} \]

The Qm is 4 veh, the over-saturation delay is computed as follows:

\[
d_2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} = \frac{0.5 \times Q_m \times CL}{V \times CL} + \frac{0.5 \times Q_m \times Q_m \times h2}{V \times CL} + \frac{Q_m \times \text{red}}{V \times CL}
\]

\[
= \frac{0.5 \times 4 \times 100}{33.27} + \frac{0.5 \times 4 \times 4 \times 2}{33.27} + \frac{4 \times 40}{33.27} = 11.29 \text{sec}
\]

Hence the travel time for this group is computed as follows:

\[
\text{Travel time} = \frac{L_{TD} - QL}{\text{speed by detector} \times 2} + \frac{L - L_{TD}}{\text{speed limit}} + d_1 + d_2 + d_4
\]

\[
= \frac{800 - 19 \times 0 + 4}{39.3 \times 5280 \div 3600} + \frac{1600 - 800}{45 \times 5280 \div 3600} + 17.65 + 11.29 + 0 = 48.13 \text{sec}
\]

Therefore, the travel time for time interval 3 is 48.13 sec. And the initial queue for next time interval is 4 veh.

**Travel Time for Time Interval 4**

In time interval 4, there is an initial queue based on the calculation of 4 veh, and the average dwelling time at the detector is smaller than 0.6sec/veh. Hence, there is no blackout on the loop detector. From Table 6-12, detected volume is 37.6 veh/in. These 37.6 veh represent the observed group whose travel time is to be calculated for time interval 4. The average detected speed is 35.97 mph.

Volume: 37.6/100*3600=1354vph;

V/C=1354/1080=1.25;

The density is Ktd =flow/speed=37.6 veh/mile;

From Equation 4-8, \((n-1) \times g \leq \frac{Q_{t-1}}{D_s} \leq n \times g\);
Since \( \frac{Q_{t-1}}{D_s} = \frac{4}{1800 \div 3600} = 30 \text{ sec} \), and \( g=60 \), \( n=1 \)

From Equation 4-9, the initial delay is

\[
d_3 = \frac{Q_{t-1}}{D_s} + (n) \times \text{red time} = \frac{4}{1800 \div 3600} + (1 \times 40) = 48 \text{ sec}
\]

Since \( V \) is greater than \( C \), use the capacity as the input volume to estimate the uniform stopped delay \( d_1 \):

\( g=8 \text{ sec}, g_2=52 \text{ sec} \)

\( h_1=100/30=3.33 \text{ sec/veh} \)

\( h_2=2 \text{ sec/veh} \)

\( S_1=36 \text{ mph}, S_2=6.5 \text{ mph} \)

\[
t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{36 \times 3.33 - 19}{36 - 6.5} = 3.4 ;
\]

\[
h_3 = \frac{t \times h_2}{t - h_2} = \frac{3.4 \times 2}{3.4 - 2} = 4.8 \text{ sec/veh}
\]

\[
m = \frac{r}{h_1} = \frac{40}{3.33} = 12 \text{ veh}
\]

\[
k = m + lq - \frac{g_1}{h_3} = 12 + 4 - \frac{2}{4.8} = 14.3
\]

\[
W_u = \frac{V - C}{k_{td} - k_q} = -2.8 \text{ mile/hour}
\]

\[
L = m + lq - \frac{g_1 + g_2}{h_3} = 12 + 4 - \frac{60}{4.80} = 3.52 ;
\]

\[
i = 4
\]

\[
t_4 - t_3 = (i - L) \times h_1 = (4 - 3.52) \times 3.33 = 1.6
\]

\[
a = 0.5 \times (k + L) \times g_2 = 0.5 \times (14.4 + 3.52) \times 52 = 464 \text{ sec}
\]

\[
b = 0.5 \times (L + i) \times (t_4 - t_3) + i \times (\text{red} - (t_4 - t_3)) = 160 \text{ sec}
\]

\[
c = 0.5 \times i \times i \times h_2 = 0.5 \times h_2 \times i^2 = 0.5 \times 2 \times 4 \times 4 = 16
\]
The average stopped delay is computed as follows:

\[
d_l = \frac{a + b + c}{V \times CL} = \frac{464 + 160 + 16}{37.6} = 17 \text{ sec}
\]

The queuing rate \( QR(\text{veh/h}) \) is:

\[
QR = \frac{dn}{dt} = (V - C - W_d \times k_d) = 380 \text{veh/h}
\]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[
Q_m = QR \times CL \approx 11 \text{veh/ln}
\]

Then the initial queue for the next time interval is

\[
Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = 15 \text{veh/ln}.
\]

The queue length is \( 29 \times 19 = 551 \text{ ft} \):

Over-saturation delay is computed as follows:

\[
d_2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} = 17.8
\]

Since \( d_3 \) is smaller than cycle length and the volume is greater than the capacity Equation 4-29 and 4-30 are used to compute the \( d_4 \). In addition, the new value of \( k \) and \( m \) should be computed based on the actual volume which is 45.7 veh per 100 seconds.

The \( k' \) and \( m' \) is 18.1 and 15 respectively.

\[
d_4 = \frac{0.5 \times r \times m' + 0.5 \times (m' + k') \times g1}{\text{Total_vehicle_in_the_Observed_Group}}
\]

\[
= \frac{0.5 \times 40 \times 15 + 0.5 \times (15 + 18.1) \times 8}{37.6} = 11.5 \text{sec}
\]
Travel time = \(\frac{L_{TD} - QL}{\text{Speed by detector} \times 2} + \frac{L - L_{TD}}{\text{Speed limit}} + d_1 + d_2 + d_4\)

\[
= \frac{800 - 19 \times 4}{35.97 \times 5280 \div 3600} + \frac{1600 - 800}{45 \times 5280 \div 3600} + 17 + 17.8 + 11.5 = 72.2 \text{ sec}
\]

Therefore, the travel time for time interval 4 is 72.2 sec and the initial queue for next time interval is 15 veh.

**Travel Time for Time Interval 5**

In time interval 5, there is an initial queue of 10 veh, and the average dwelling time at the detector is smaller than 0.6 sec/veh. Hence, there is no blackout at the loop detector. From Table 6-12, the detected volume is 45.66 veh/ln, and the average detected speed is 27.87 mph.

Volume: \(\frac{39.05}{100} \times 3600 = 1406\) vph;

\(V/C = \frac{1406}{1080} = 1.3\)

The density is \(K_{td} = \frac{\text{flow}}{\text{speed}} = 50.4\) veh/mile;

From Equation 4-8, \((n - 1) \times g \leq \frac{Q_{r-1}}{D_s} \leq n \times g\);

\[
\frac{Q_{r-1}}{D_s} = \frac{15}{1800 \div 3600} = 30 \text{ sec}, \text{ and } g = 60, n = 1
\]

From Equation 4-9, the initial delay is

\[
d_3 = \frac{Q_{r-1}}{D_s} + (n) \times \text{red time} = \frac{15}{1800 \div 3600} + (1) \times 40 = 70 \text{ sec}
\]

\(g_1 = 30 \text{ sec}, \text{ and } g_2 = 30 \text{ sec}\)

Since \(V\) is greater than Capacity, use the capacity as the incoming volume to estimate the uniform stopped delay.

\(h_1 = \frac{100}{30} = 3.33 \text{ sec/veh}\)
h2 = 2 sec/veh

S1 = 27.8, S2 = 6.5 mph

\[
t = \frac{S1 \times h1 - 19}{(S1 - S2)} = \frac{27.8 \times 3.33 - 19}{27.8 - 6.5} = 3.45;
\]

\[
h3 = \frac{t \times h2}{t - h2} = \frac{3.45 \times 2}{3.45 - 2} = 4.74 \text{ sec/veh}
\]

\[
m = \frac{r}{h1} = \frac{40}{3.33} = 12 \text{ veh}
\]

\[
k = m + Iq - \frac{g1}{h3} = 12 + 15 - \frac{30}{4.72} = 20.7
\]

\[
L = m + Iq - \frac{g1 + g2}{h3} = 14.35;
\]

\[i = 15\]

\[t4 - t3 = (i - L) \times h1 = (15 - 14.35) \times 3.33 = 2.2\]

\[a = 0.5 \times (k + L) \times g2 = 0.5 \times (20.67 + 14.35) \times 30 = 525 \text{ sec}\]

\[b = 0.5 \times (L + i) \times (t4 - t3) + i \times (\text{red} - (t4 - t3)) = 599 \text{ sec}\]

\[c = 0.5 \times i \times i \times h2 = 0.5 \times h2 \times i^2 = 0.5 \times 2 \times 15 \times 15 = 225\]

The average stopped delay

\[d1 = \frac{a + b + c}{V \times CL} = 34.5 \text{ sec/veh}\]

\[W_a = \frac{V - C}{k_{id} - k_q} = -3.86 \text{ mile/hour}\]

The queuing rate QR (veh/h) is:

\[QR = \frac{dn}{dt} = (V - C - W_a \times k_w) = 520 \text{ veh/h}\]

The number of the vehicles in queue which is built during the observed cycle length t will be:

\[Q_m = QR \times CL = 520 \times \frac{100}{3600} \approx 14 \text{ veh/ln}\]
Then the initial queue for the next time interval is

\[ Q_{t-1} = \max(0, \sum_{m=1}^{i} Q_{m}) = 15 + 14 = 29 \text{veh} / \ln. \]

The queue length is 19*29=551 ft:

Over-saturation delay is computed as follows:

\[
d_2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} = \frac{0.5 \times Q_m \times CL}{V \times CL} + \frac{0.5 \times Q_m \times Q_m \times h}{V \times CL}
\]

\[
= \frac{0.5 \times 14 \times 100}{39} \times + \frac{0.5 \times 14 \times 14 \times 2}{39} \times = 23 \text{sec/veh}
\]

Since \( d_3 \) is smaller than cycle length and the volume is greater than the capacity Equation 4-29 and 4-30 are used to compute the \( d_4 \). In addition, the new value of \( k \) and \( m \) should be computed based on the actual volume which is 45.7 veh per 100 seconds.

The \( k' \) and \( m' \) is 27.8 and 15.6 respectively.

\[
d_4 = \frac{0.5 \times r \times m' + 0.5 \times (m' + k') \times g_1}{\text{Total \_vehicle \_in \_the \_Observed \_Group}}
\]

\[
= \frac{0.5 \times 40 \times 15.6 + 0.5 \times (15.6 + 27.8) \times 30}{45.66} = 24.7 \text{sec}
\]

Travel time = \[
\frac{L_{TD} - QL}{\text{speed \_by \_detector} \times 2} + \frac{L - L_{TD}}{\text{Speed \_limit}} + d_1 + d_2 + d_4
\]

\[
= \frac{800 - 19 \times 15}{27.9 \times 5280 + 3600} + \frac{1600 - 800}{45 \times 5280 + 3600} + 34.6 + 23 + 24.7 = 107 \text{sec}
\]

Hence, the travel time for time interval 5 is 107sec. And the initial queue for next time interval is 29 veh.

**Travel Time for Time Interval 6**

In the time interval 6, there is an initial queue of 29 vehicles. And the average dwelling time 0.67 is greater than 0.6sec/veh but smaller than 0.7 sec/veh. Hence, it is
the critical value for a blackout situation. Hence, there is a blackout situation and the average incoming group of vehicles is based on the detected volume of the upstream link i-1 in time intervals 5 and 6. Algorithm 3 in chapter 5 is used to estimate the travel time in this interval.

There is no acceptable time period to estimate the t% before 600 seconds since we can not use the data from the detector in the middle of the cycle length. Hence use the data in time 1200 seconds to estimate the t%. At the end of 1200 seconds, there is no blackout, the total number of vehicles detected on link i-1 from 0-1200 seconds is 823 and 809 on link i. Hence the t%=(809-823)/823=-1.7%

The average volume of link i-1 in time interval 5 and 6 is
\[
\frac{(45.77+40)}{2}\times\frac{3600}{100}=1548\text{vph}
\]

But the capacity of link i-1 is only 1395vph.

Hence, the incoming volume in time interval 6 on link i is
\[
1395*(1-1.7%)=1371\text{vph}
\]

V/C=1371/1080=1.26;

From Equation 4-8, \((n-1)\times g \leq \frac{Q_{i-1}}{D_s} \leq n\times g\);

Since \[
\frac{Q_{i-1}}{D_s} = \frac{29}{1800 \div 3600} = 58\text{sec},\text{and } g=60, n=1
\]

From Equation 4-9, the initial delay is
\[
d_3 = \frac{Q_{i-1}}{D_s} + (n)\times\text{red time}= \frac{29}{1800 \div 3600} + (2)\times40 = 98\text{sec}
\]

The number of the vehicles in queue which is built during the observed cycle length t will be:
\[ QL_{\text{in}_i} + (V - C) \times CL = 29 + (1371 - 1080) \times 100/3600 = 37 \text{ veh/ln} \]

The queue length is 19*37 = 703 ft.

Since there is a blackout situation, we can assume all vehicles in the observed group are in the queue when the first vehicle of the group arrived at the intersection.

g1 = 58 sec, and g2 = 2 sec

h1 = 100/30 = 3.33 sec/veh

h2 = 2 sec/veh

\[ m = C \times CL = 30 \text{ veh} \]

\[ i = m - \frac{g2}{h2} = 30 - \frac{2}{2} = 29 \text{ veh} \]

The area of A is

\[ a = 0.5 \times (i + m) \times g2 = 0.5 \times (29 + 30) \times 2 = 59 \text{ sec} ; \]

The area of B and C are

\[ b = r \times i = 29 \times 40 = 1160 \text{ sec} ; \]

\[ c = 0.5 \times (i \times h2) \times i = 0.5 \times 29^2 = 841 \text{ sec} \]

The average uniform stopped delay

\[ d1 = \frac{a + b + c}{V \times CL} = \frac{59 + 1160 + 841}{38.1} = 54 \text{ sec/veh} \]

\[ i_1 = Qm - g2/h2 = 8 - 2/2 = 7 \text{ veh} \]

Over-saturation delay is computed as follows:

\[ d2 = \frac{\text{area}(A) + \text{area}(B) + \text{area}(C) + \text{area}(D)}{V \times CL} \]

\[ = \frac{0.5 \times Qm \times CL}{V \times CL} + \frac{0.5 \times (i_1^2 + Q_m) \times g2}{V \times CL} + \frac{r \times i}{V \times CL} + \frac{0.5 \times i_1 \times i \times h2}{V \times CL} \]

\[ = 19.34 \text{ sec/veh} \]

Since d3 is close to cycle length, Equation 4-33 is used to compute the d4.

\[ d4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d3 - CL = d3 - 0.5 \times CL = 98 - 50 = 48 \text{ sec} \]
Travel time = \( \frac{L - QL}{\text{Speed limit} ÷ 2} + d1 + d2 + d3 \)

\[
= \frac{1600 - 29 \times 19}{45 \times 5280 ÷ 3600 ÷ 2} + 54.1 + 19.4 + 48 = 155.2 \text{ sec}
\]

Therefore, the travel time for time interval 6 is 155.2 seconds. And the initial queue for next time interval is 37 veh.

**Travel Time for Time Interval 7**

In time interval 7, there is an initial queue of 37 veh, and the average dwelling time is bigger than 0.6 sec/veh. Hence, there is a blackout situation during this time interval too. The detected traffic data is not reliable due to the blackout situation. Therefore the incoming group of vehicles is based on the average upstream link volume in time intervals 6 and 7.

The detected volume on link i-1 during time interval 6 is 40veh/ln and 24veh/ln the in time interval 7. The average is (40 + 24)/2 = 32 veh/ln. Based on the pervious observation on link i-1, we can assume the initial queue for time period 6 is approximately 19.8 veh according to the early computation. Hence, \( V_{i-1} + Vq \) is bigger than the capacity of link i-1 which is 1395veh/h/ln.

Therefore, the incoming volume for link i is 1395*(1-0.017) = 1371 veh/h/ln

\( V/C = 1371/1080 = 1.26 \);

From Equation 4-8, \( (n - 1) \times g \leq \frac{Q_{i-1}}{D_s} \leq n \times g \);

Since \( \frac{Q_{i-1}}{D_s} = \frac{37}{1800 ÷ 3600} = 74 \text{ sec} \), and \( g = 60, n = 2 \).
From Equation 4-9, the initial delay is

\[ d_3 = \frac{Q_{r-1}}{D_s} + (n) \times red\_time = \frac{37}{1800 \div 3600} + (2) \times 40 = 154 \text{ sec} \]

Since the Ktd in this time interval is not reliable due to the blackout, the shockwave method is not good in this situation to estimate the queue length. A base method is used instead of it.

At the end of time interval 7, the number of vehicle in queue is

\[ Q_{L_{in\_time\_i-1}} + (V - C) \times CL = 37 + (1371-1080) \times \frac{100}{3600} = 45 \text{ veh/ln} \]

Then the initial queue for the next time interval is 45

The queue length is 19\times45=855\text{ ft},

\[ g_1=14\text{ sec}, \text{ and } g_2=46 \text{ sec} \]

Since \( V \) is greater than Capacity, use the capacity as the incoming volume to estimate the uniform stopped delay. And since the \( d_3 \) is greater than a cycle length, all vehicles in observed group are in the queue when dissipating the intersection is assumed.

\[ h_1=\frac{100}{30}=3.33 \text{ sec/veh} \]

\[ h_2=2 \text{ sec/veh} \]

\[ m = C \times CL = 30\text{ veh} \]

\[ i = m - \frac{g_2}{h_2} = 30 - \frac{46}{2} = 7\text{ veh} \]

The area of A is

\[ a = 0.5 \times (i + m) \times g_2 = 0.5 \times (7 + 30) \times 46 = 851\text{ sec} ; \]

The area of B and C are

\[ b = r \times i = 7 \times 40 = 280\text{ sec} ; \]
\[ c = 0.5 \times (i \times h2) \times i = 0.5 \times h2 \times i^2 = 0.5 \times 2 \times 7^2 = 49 \text{ sec} \]

The average uniform stopped delay \[ d1 = \frac{a + b + c}{V \times CL} = \frac{851 + 280 + 49}{38.1} = 31 \text{ sec/veh} \]

Over-saturation delay is computed as follows:

\[ d2 = \frac{\text{area}(B) + \text{area}(C)}{V \times CL} = \frac{0.5 \times Q_m \times CL}{V \times CL} + \frac{0.5 \times Q_m \times h2}{V \times CL} \]
\[ = \frac{0.5 \times 8 \times 100}{38.1} + \frac{0.5 \times 8 \times 8 \times 2}{38.1} = 12.2 \text{ sec/veh} \]

Since \( d3 \) is greater than cycle length, Equation 4-33 is used to compute the \( d4 \).

\[ d4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d3 - CL = d3 - 0.5 \times CL = 154 - 50 = 104 \text{ sec} \]

Since the queue length is longer than the location of loop detector, the travel time is computed as follows:

\[ \text{Travel-time} = \frac{L - QL}{\text{Speed-limit}} \div 2 + d1 + d2 + d4 \]
\[ = \frac{1600 - 37 \times 19}{45 \times 5280 \div 3600 \div 2} + 31 + 12.2 + 104 = 174 \text{ sec} \]

Therefore, the **travel time for time interval 7** is 174 seconds. And the initial queue for next time interval is 45 veh.

**Travel Time for Time Interval 8**

In time interval 8, there is an initial queue of 45 veh, and the average dwelling time is bigger than 0.6 sec/veh. Hence, there is a blackout situation during this time interval too. The detected traffic data is not reliable due to the blackout situation. Therefore the incoming group of vehicles is based on the average upstream link
volume in time intervals 7 and 8.

The turning movement: the turning movement is -1.7%.

And the volume detected by the link i-1 during time interval 7 is 23.88 veh/ln and 12.77 veh/ln in time interval 8. The initial queue for time interval 7 is approximately 8.3 as computed easily. Hence, the incoming volume is

\[(23.88+12.77)/2+8.33)*3600/100=967 \text{ (veh/h/ln)}\]

It is smaller than the capacity of link i-1.

Therefore, 967 veh/h/ln represents the incoming volume of link i in time interval 8.

From Equation 4-8, \((n-1) \times g \leq \frac{Q_{i-1}}{D_s} \leq n \times g\);

Since \(\frac{Q_{i-1}}{D_s} = \frac{45}{1800 \div 3600} = 90 \text{ sec}\), and \(g=60, n=2\)

From Equation 4-9, the initial delay is

\[d_3 = \frac{Q_{i-1}}{D_s} + (n) \times \text{red time} = \frac{45}{1800 \div 3600} + (2) \times 40 = 170 \text{ sec}\]

At the end of time interval 8, the number of vehicle in queue is

\[Q_{L_{in\_time\_i-1}} + (V - C) \times CL = 45 + (967-1080)*100/3600 = 41 \text{ veh/ln}\]

\(g_1=30\text{ sec}, \text{ and } g_2=30 \text{ sec}\)

Since the \(d_3\) is greater than a cycle length, all vehicles in observed group are in the queue when dissipating the intersection is assumed.

\(h_2=2 \text{ sec/veh}\)

\[m = V \times CL = 26.86 \text{ veh}\]
The area of A is
\[ a = 0.5 \times (i + m) \times g^2 = 0.5 \times (11.86 + 26.86) \times 30 = 581 \text{ sec} ; \]

The area of B and C are
\[ b = r \times i = 11.86 \times 40 = 474.6 \text{ sec} ; \]
\[ c = 0.5 \times (i \times h^2) \times i = 140.8 \text{ sec} \]

The average uniform stopped delay
\[ d1 = \frac{a + b + c}{V \times CL} = \frac{581 + 474.6 + 140.8}{10 \times 5280} = 44.5 \text{ sec} / \text{veh} \]

\[ d2 = 0 \text{ sec} \quad \text{since } Q_m \text{ is equal to zero} \]

Since \( d3 \) is greater than cycle length, Equation 4-33 is used to compute the \( d4 \).

\[ d4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d3 - CL = \frac{170 - 50}{5280} = 120 \text{ sec} \]

\[ Travel - time = \frac{L - QL}{\text{Speed limit} \div 2} + d1 + d2 + d4 \]
\[ = \frac{1600 - 45 \times 19}{45 \times 5280 \div 3600 \div 2} + 44.5 + 0 + 120 = 187.1 \text{ sec} . \]

Therefore, the **travel time for time interval 8** is 187.1 seconds. And the initial queue for next time interval is 41 veh.

**Travel Time for Time Interval 9**

In the time interval 9, the average dwelling time is bigger than 0.7 sec/veh. Hence, there is a blackout situation. The detected traffic data is not reliable due to the blackout situation. Therefore the incoming group of vehicles is based on the average upstream link volume in time intervals 8 and 9.

The turning movement: the turning movement is -1.7%.
And the detected volume by the link i-1 during time interval 8 is 10.55 veh/ln and 8.33 veh/ln in time interval 9. The initial queue for time interval 8 on link i-1 is approximately 0. Hence, the incoming volume is \((10.55+8.33)/2*3600/100=380\) (veh/h/ln). It is smaller than the capacity of link i-1.

\[
V/C=380*(1-1.7%)/1080=0.34;
\]

From Equation 4-8, \((n-1) \times g \leq \frac{Q_{t-1}}{D_s} \leq n \times g\);

Since \(\frac{Q_{t-1}}{D_s} = \frac{41}{1800 + 3600} = 82 \text{ sec}, \text{and } g=60, n=2\)

From Equation 4-9, the initial delay is

\[
d_3 = \frac{Q_{t-1}}{D_s} + (n) \times \text{red time} = \frac{41}{1800 + 3600} + (2) \times 40 = 162 \text{ sec}
\]

At the end of time interval 9, the number of vehicle in queue is

\[
QL_{in\_time\_i-1} + (V - C) \times CL = 41 + (373-1080)*100/3600 = 21 \text{ veh/ln}
\]

g1=22sec, and g2=38 sec

Since the d3 is greater than a cycle length, all vehicles in observed group are in the queue when dissipating the intersection is assumed.

h2=2 sec/veh

\[
m = V \times CL = 10.37 \text{ veh}
\]

\[
i = m - \frac{g_2}{h_2} < 0
\]

Hence, all the vehicles will dissipate the intersection in g2.

The area of A is

\[
a = 0.5 \times m \times m \times h_2 = 0.5 \times 10.37 \times 10.37 \times 2 = 107 \text{ sec};
\]

The area of B and C are
\[ b = c = 0; \]

The average uniform stopped delay \[ d_1 = \frac{a + b + c}{V \times CL} = \frac{107}{10.37} = 10.37 \text{ sec/veh} \]

\[ d_2 = 0 \text{ sec} \quad \text{since Qm is smaller than zero} \]

Since \( d_3 \) is greater than cycle length, Equation 4-33 is used to compute the \( d_4 \).

\[ d_4 = \frac{0.5 \times V \times CL^2}{V \times CL} + d_3 - CL = d_3 - 0.5 \times CL = 162 - 50 = 112 \text{ sec} \]

\[
\text{Travel time} = \frac{L - QL}{\text{Speed limit}} + d_1 + d_2 + d_4 \\
= \frac{1600 - 43 \times 19}{45 \times 5280 \div 3600 \div 2} + 10.37 + 0 + 112 = 147 \text{ sec}.
\]

Therefore, the **travel time for time interval 9 is 147 sec** and the initial queue for next time interval is 21 veh.

**Travel Time for Time Interval 10**

In time interval 10, there is an initial queue of 21 veh based on the calculation of the previous time period. And the average dwelling time is smaller than 0.7 sec/veh.

Hence, there is no blackout situation. And from Table 6-12, the detected volume is 7.6 veh/ln. These 7.6 veh are the observed group which represents the travel time at time interval 10. The average speed detected by detector is 41.95 mph.

Volume: \( 7.6/100 \times 3600 = 274 \text{ vph} \);

\( V/C = 274/1080 = 0.25; \)

The density is \( \text{Ktd} = \text{flow/speed} = 6.53 \text{ veh/mile} \);

From Equation 4-8, \((n - 1) \times g \leq \frac{Q_{n-1}}{D_s} \leq n \times g ;\)
Since \( \frac{Q_{t-1}}{D_s} = \frac{21}{1800 ÷ 3600} = 42 \) sec., and \( g=60, n=1 \)

From Equation 4-9, the initial delay is

\[
d_3 = \frac{Q_{t-1}}{D_s} + (n) \times \text{red time} = \frac{21}{1800 ÷ 3600} + (1) \times 40 = 82 \text{ sec}
\]

\[
W_d = \frac{C - V}{k_q - k_{id}} = 6.27 \text{ mile/hour}
\]

The queuing rate \( QR(\text{veh/h}) \) is:

\[
QR = \frac{dn}{dt} = (V - C - W_d \times k_{id}) = -846 \text{ veh/h}
\]

The number of the vehicles in queue which is built during the observed cycle length \( t \) will be:

\[
Q_m = QR \times CL = -846 \times \frac{100}{3600} \approx -24 \text{ veh/ln}
\]

Then the initial queue for the next time interval is

\[
Q_{t-1} = \max(0, \sum_{m=1}^{t} Q_m) = \min(0, 23 - 24) = 0 \text{ veh/ln}.
\]

The queue length is \( 0 \times 19 = 0 \) ft.

Since the \( d_3 \) is smaller than a cycle length and the volume of the last observed group is smaller than the capacity, use the case 4 of the uniform stopped delay, but in the time interval 9, the \( t_4-t_3 \) is equal to zero.

\( g_1=42 \text{ sec}, g_2=18 \text{ sec} \)

\( h_1=100/7.6=13.13 \text{ sec/veh} \)

\( h_2=2 \text{ sec/veh} \)

\( S_1=42 \text{ mph}, S_2=6.5 \text{ mph} \)
\[ t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = 15; \]

\[ h_3 = \frac{t \times h_2}{t - h_2} = \frac{15 \times 2}{15 - 2} = 2.3 \text{ sec/veh} \]

\[ L = m + lq - \frac{g_1 + g_2}{h_3} = -1.9 \]

\[ k = m + lq - \frac{g_1}{h_3} = \frac{40}{12} + 21 - \frac{42}{2.3} = 6.1 \text{ veh} \]

Since \( L \) is smaller than zero, all vehicles in the observed group will dissipate the intersection in \( g_2 \).

The uniform stopped delay for this observed group is computed as follows:

\[ d_1 = \frac{0.5 \times Q_{\text{max}} \times Q}{\text{Total Arrival}} = \frac{0.5 \times k \times (k \times h_3)}{7.6} = 5.7 \text{ sec/veh}; \]

\( d_2 = 0 \), since \( V \) is smaller than the capacity.

Since \( d_3 \) is smaller than the cycle length and the volume is smaller than the capacity in this time interval, Equation 4-29 and 4-30 are used to computed the \( d_4 \) with the same \( k \) and \( m \) values.

\[ d_4 = \frac{0.5 \times r \times m + 0.5 \times (m + k) \times g_1}{\text{Total vehicle in the Observed Group}} = \frac{0.5 \times 40 \times 3.04 + 0.5 \times (3.03 + 5.8) \times 42}{7.6} = 32.5 \text{ sec} \]

\[ \text{Travel time} = \frac{L_{TD} - QL}{\text{Speed by detector } \times 2} + \frac{L - L_{TD}}{\text{Speed limit}} + d_1 + d_2 + d_4 \]

\[ = \frac{800 - 19 \times 23}{41.95 \times 5280 + 3600} + \frac{1600 - 800}{45 \times 5280 + 3600} + 6.1 + 0 + 32.5 = 56.3 \text{ sec} \]

Therefore, the travel time for time interval 10 is 53.1 sec and the initial queue for next time interval is 0 veh.

Figure 6-5 is the illustration of travel time model components for 10 time period analysis with 120 seconds data updates.
![Travel Time Comparison with 120 Time Interval Update](image)

Figure 6 - 5 Travel Time Comparison with 120 Time Interval Update
6.5 Bottleneck on Downstream Link

In this situation, there is a bottleneck at the intersection which is caused by the traffic jam of the downstream link i+1. This influences the capacity of link i as discussed in Chapter 5. The goal of this simulation is to validate the determination of the new intersection capacity of link i. The volume detected by the detector at link i+1 minus the volume of turning vehicles (V_{\text{turn}} as discussed and computed earlier) represents the maximum departure volume of link i. The maximum departure volume of link i is the new capacity of link i.

In order to create a bottleneck in the simulation, the number of lanes on link i+1 is changed from 3 to 2 and the link length was dropped from 1600 ft to 400ft. The loop detector on link i+1 is located at the 200 ft from the stop line of link i+1. Another loop detector on link i is located at 5ft from the stop line of link i in order to make sure that the departure rate on link i is consistent with the detected volume on link i+1. Table 6-13 shows the simulation data from both loop detectors. The detected volumes are similar which permits us to use the detected volumes on link i+1 to compute the capacity on link i. There are no turning movements in this simulation.

<table>
<thead>
<tr>
<th>Time period</th>
<th>Veh detected</th>
<th>Time period</th>
<th>Veh detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
<td>2</td>
<td>42</td>
</tr>
<tr>
<td>3</td>
<td>47</td>
<td>3</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>4</td>
<td>47</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>5</td>
<td>42</td>
</tr>
</tbody>
</table>

In Table 6-13, the number of dissipated vehicles on link i is almost the same as
the number of detected vehicles on link i+1.

Therefore, the new capacity of the link i for time interval n can be represented as discussed in Chapter 5: 
\[ C = \frac{V_{i+1} \times N_{i+1} - V_{turn}}{N_i} ; \]

For example, the new capacity of link i for time interval 1 can be computed as follows:
\[ C = \frac{V_{i+1} \times N_{i+1} - V_{turn}}{N_i} = \frac{45}{3} = 15 \text{veh/h/ln} ; \]

The capacity for the remaining intervals is similarly computed. Once the new capacity of link i is determined, the rest of the calculations remain the same.

6.6 Comparison of CORSIM results with proposed Algorithms

This section is divided into the following parts:

a) Understanding the outputs from CORSIM

b) Understanding and fixing the CORSIM results to match the objectives of this study.

c) Comparing the adjusted CORSIM results with the algorithms results.

6.6.1 The relevant Outputs from CORSIM

The CORSIM outputs that are of interest to this study are:

- Vehicle Trips - The number of vehicles that have been discharged from the link for each time interval.
- Vehicle Miles - The vehicle trips times the length of link.
• Total Time (veh-min) - Total time on the link for all vehicles for a defined time interval.

• Average Speed (miles per hr) - Total vehicle miles divided by the total travel time.

• Number of vehicles detected by the loop detector (V*CL).

• Control Delay per vehicle for all the vehicles occupying the link for a defined time interval, (sec per veh).

6.6. 2-Adjusting the CORSIM Outputs

Before starting the comparison phase, an independent step is carried out to make sure that the computed travel times and speeds in CORSIM are reliable. The average travel speed in CORSIM is statistically computed at the end of each time interval as the ratio of vehicles-miles traveled divided by the total vehicle travel times. Sometimes due a rapid drop in incoming volume the computed speed by CORSIM does not respond quickly to this sudden change and the average travel time increases instead of decreasing with the drop in volume as shown in intervals 9 and 10 of Table 6-14.
Table 6 - 14 CORSIM Data

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Average Speed in CORSIM(mph)</th>
<th>Travel time by CORSIM(sec)</th>
<th>Travel time by Algorithm(sec)</th>
<th>speed by detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.4</td>
<td>53.47593583</td>
<td>43.687095</td>
<td>38.3</td>
</tr>
<tr>
<td>2</td>
<td>23.8</td>
<td>45.83651642</td>
<td>40.16358201</td>
<td>40.49672131</td>
</tr>
<tr>
<td>3</td>
<td>26.8</td>
<td>40.70556309</td>
<td>41.24545839</td>
<td>37.59139785</td>
</tr>
<tr>
<td>4</td>
<td>21.8</td>
<td>50.04170142</td>
<td>87.27552627</td>
<td>37.06818182</td>
</tr>
<tr>
<td>5</td>
<td>18.2</td>
<td>59.94005994</td>
<td>140.1613914</td>
<td>33.25620438</td>
</tr>
<tr>
<td>6</td>
<td>13.7</td>
<td>79.6284008</td>
<td>205.4808915</td>
<td>23.56792453</td>
</tr>
<tr>
<td>7</td>
<td>10.6</td>
<td>102.915952</td>
<td>235.6443025</td>
<td>11.93846154</td>
</tr>
<tr>
<td>8</td>
<td>8.7</td>
<td>125.3918495</td>
<td>239.991279</td>
<td>8.28</td>
</tr>
<tr>
<td>9</td>
<td>7.1</td>
<td>153.6491677</td>
<td>185.480762</td>
<td>26.00714286</td>
</tr>
<tr>
<td>10</td>
<td>9.7</td>
<td>112.4648547</td>
<td>98.96646764</td>
<td>41.612</td>
</tr>
<tr>
<td>11</td>
<td>30.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The input volume by the user during time intervals 9 and 10 dropped rapidly as shown in Table 6-1. In interval 8, there was a black out condition and the incoming volume started to decrease. Hence, the queue at the intersection should be decreased too. As a result, the average speed on the link should increase and the total travel time on link i should be reduced. A look at the detector output shows that the average detected speed within these two time intervals has increased. On the contrary, the average speed on link i in time intervals 9 and 10 in CORSIM have decreased, which is not reasonable.

In Table 6-1, the input volume during time intervals 9, 10, and 11 are very similar. The speed at time interval 11 is 30.8mph in CORSIM, where no queue at the intersection is realized through the CORSIM visualizer. So, if the speed at interval 11 is considered correct, then we can interpolate the other two speeds for intervals 9 and 10 by taking the speeds of intervals 8 and 11 as the end points. After executing the interpolation procedure the speeds in intervals 9 and 10 are 16.00 and 23.3 mph respectively as shown in Table 6-15.
Now, we can use the new average speed to get the new total travel time on link i in time periods 9 and 10 as follows: \( \frac{\text{veh} \cdot \text{miles}}{\text{average} \cdot \text{speed}} \).

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Average Speed in CORSIM (mph)</th>
<th>Travel time by CORSIM (sec)</th>
<th>Speed by detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.4</td>
<td>53.5</td>
<td>38.3</td>
</tr>
<tr>
<td>2</td>
<td>23.8</td>
<td>45.8</td>
<td>40.5</td>
</tr>
<tr>
<td>3</td>
<td>26.8</td>
<td>40.7</td>
<td>37.6</td>
</tr>
<tr>
<td>4</td>
<td>21.8</td>
<td>50</td>
<td>37.1</td>
</tr>
<tr>
<td>5</td>
<td>18.2</td>
<td>59.9</td>
<td>33.3</td>
</tr>
<tr>
<td>6</td>
<td>13.7</td>
<td>79.6</td>
<td>23.6</td>
</tr>
<tr>
<td>7</td>
<td>10.6</td>
<td>102.9</td>
<td>11.9</td>
</tr>
<tr>
<td>8</td>
<td>8.7</td>
<td>125.4</td>
<td>8.3</td>
</tr>
<tr>
<td>9</td>
<td>16.0</td>
<td>68.2</td>
<td>26.0</td>
</tr>
<tr>
<td>10</td>
<td>23.3</td>
<td>46.8</td>
<td>41.6</td>
</tr>
</tbody>
</table>

6.6.3 Manipulating the CORSIM Output to Fit our Objectives

The control delay in CORSIM is the average control delay for all the vehicles occupying link i during a time interval. It is composed of two parts: a) the intersection delay experienced by the vehicles that can clear the intersection during this time interval b) the deceleration delay or the stopped delay experienced by those vehicles that can not clear the intersection during this time interval. CORSIM calculates only the average delay for one time interval. However, as we have explained earlier, the travel time of the observed group of vehicles may last for more than one time interval in order to clear the intersection. Hence, CORSIM’s control delay under estimates the intersection control delay obtained from our algorithms for the observed group, particularly when there is an initial queue at the intersection.
Similarly, the average speed in CORSIM can not be used to compute the travel time of the observed group since it only represents the average speed on the link in one time interval.

In conclusion, CORSIM does not compute the extra time needed by the observed group to clear the intersection beyond a time interval, which is the initial queue delay which we referred to in Chapters 3 and 4 as d3.

To address this issue the following procedure is adopted:

i) Determine the average time it takes the observed group of vehicles to occupy the link, assuming that the average time of the observed group is represented by the average time of all the vehicles occupying the link for that particular time interval, and

ii) Determine the average time it takes the initial queue to clear the intersection d3, irrespective of how many time intervals it requires.

The average travel time for all vehicles on the link during a time interval can be computed as follows:

Let \( t_{ave} \) be the average time on the link during the observed time interval in CORSIM. 

\[
 t_{ave} = \frac{\text{Total travel time for all vehicles}}{\text{Inco min g vehicles + vehicles in queue}}. 
\]

Where;
Number of incoming vehicles is the number of vehicles detected by the detector during the time interval.

The vehicles in the queue are counted visually from the visualizer.

The initial queue, the detected incoming volume, and the $t_{ave}$ are computed from CORSIM output and are shown in Table 6-16.

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Total time (sec/ln)</th>
<th>Initial queue</th>
<th>Income vehicle veh/ln/CL</th>
<th>$t_{ave}$(sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1536</td>
<td>14</td>
<td>36.67</td>
<td>30.3</td>
</tr>
<tr>
<td>5</td>
<td>2012</td>
<td>19</td>
<td>45.67</td>
<td>31.1</td>
</tr>
<tr>
<td>6</td>
<td>2440</td>
<td>33</td>
<td>35.33</td>
<td>35.7</td>
</tr>
<tr>
<td>7</td>
<td>2960</td>
<td>39</td>
<td>35.73</td>
<td>39.6</td>
</tr>
<tr>
<td>8</td>
<td>3740</td>
<td>47</td>
<td>25.2</td>
<td>51.8</td>
</tr>
<tr>
<td>9</td>
<td>1657</td>
<td>39</td>
<td>9.33</td>
<td>34.3</td>
</tr>
<tr>
<td>10</td>
<td>1062</td>
<td>19</td>
<td>8.33</td>
<td>38.9</td>
</tr>
</tbody>
</table>

The initial queue delay $d_3$ has been computed manually based on the visual observations from CORSIM output and based on the calculations provided in Chapter 4.

Combining these two delays, the total travel time for the observed group in CORSIM for each time interval is computed and is shown in Table 6-17.

The adjusted CORSIM results would remain the same irrespective of the loop detector time interval update because the cycle length at the intersection is 100 secs for all the three experiments.
Table 6 - 17 Revised Travel time of the observed group in CORSIM

<table>
<thead>
<tr>
<th>Time interval</th>
<th>blackout</th>
<th>Travel time by CORSIM (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N</td>
<td>53.5</td>
</tr>
<tr>
<td>2</td>
<td>N</td>
<td>45.8</td>
</tr>
<tr>
<td>3</td>
<td>N</td>
<td>40.7</td>
</tr>
<tr>
<td>4</td>
<td>N</td>
<td>53.5</td>
</tr>
<tr>
<td>5</td>
<td>N</td>
<td>62.2</td>
</tr>
<tr>
<td>6</td>
<td>N</td>
<td>131.7</td>
</tr>
<tr>
<td>7</td>
<td>Y</td>
<td>147.6</td>
</tr>
<tr>
<td>8</td>
<td>Y</td>
<td>175.8</td>
</tr>
<tr>
<td>9</td>
<td>N</td>
<td>157.7</td>
</tr>
<tr>
<td>10</td>
<td>N</td>
<td>58.4</td>
</tr>
</tbody>
</table>

6.6. 4 Comparison of Results

The comparison of the travel time of the observed group in CORSIM with those of the algorithms for different detector outputs are shown in Table 6-18 and in Figure 6-6.

Table 6 - 18 Travel time in CORSIM Vs. the Algorithms travel time for 100,120 and 60 seconds Update

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Travel time by CORSIM (sec)</th>
<th>Travel time by Algorithm (100 sec)</th>
<th>Travel time by Algorithm (120 sec)</th>
<th>Travel time by Algorithm (60 sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53.5</td>
<td>43.7</td>
<td>39.4</td>
<td>39.7</td>
</tr>
<tr>
<td>2</td>
<td>45.8</td>
<td>40.2</td>
<td>44.0</td>
<td>42.9</td>
</tr>
<tr>
<td>3</td>
<td>40.7</td>
<td>41.2</td>
<td>48.0</td>
<td>45.2</td>
</tr>
<tr>
<td>4</td>
<td>53.5</td>
<td>61.3</td>
<td>72.2</td>
<td>67.4</td>
</tr>
<tr>
<td>5</td>
<td>62.2</td>
<td>104.6</td>
<td>107.1</td>
<td>104.5</td>
</tr>
<tr>
<td>6</td>
<td>131.7</td>
<td>157.7</td>
<td>155.2</td>
<td>157.8</td>
</tr>
<tr>
<td>7</td>
<td>147.6</td>
<td>185.6</td>
<td>174.3</td>
<td>172.9</td>
</tr>
<tr>
<td>8</td>
<td>175.8</td>
<td>190.0</td>
<td>187.1</td>
<td>178.8</td>
</tr>
<tr>
<td>9</td>
<td>157.7</td>
<td>135.5</td>
<td>147.3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>58.4</td>
<td>54.1</td>
<td>56.5</td>
<td></td>
</tr>
</tbody>
</table>
The Mean Absolute Error (MAE) is used to compare the fitness of the algorithm results with revised CORSIM results. The Mean Absolute Error is calculated as

\[ MAE = \frac{1}{n} \sum_{i=1}^{n} |\text{Observed} - \text{Estimated}|. \]

The MAE and the average percent of difference are shown in Table 6-19.

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Difference (100)</th>
<th>% of difference</th>
<th>Difference (120)</th>
<th>% of difference</th>
<th>Difference (60 sec)</th>
<th>% of difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.8</td>
<td>18.3</td>
<td>14.1</td>
<td>26.4</td>
<td>13.8</td>
<td>25.8</td>
</tr>
<tr>
<td>2</td>
<td>5.7</td>
<td>12.4</td>
<td>1.8</td>
<td>3.9</td>
<td>2.9</td>
<td>6.3</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>1.3</td>
<td>7.3</td>
<td>18.0</td>
<td>4.5</td>
<td>11.0</td>
</tr>
<tr>
<td>4</td>
<td>7.8</td>
<td>14.5</td>
<td>18.7</td>
<td>35.0</td>
<td>13.9</td>
<td>26.0</td>
</tr>
<tr>
<td>5</td>
<td>42.4</td>
<td>68.2</td>
<td>44.9</td>
<td>72.2</td>
<td>42.3</td>
<td>68.0</td>
</tr>
<tr>
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<td>26.0</td>
<td>19.7</td>
<td>23.5</td>
<td>17.8</td>
<td>26.1</td>
<td>19.8</td>
</tr>
<tr>
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<td>38.0</td>
<td>25.8</td>
<td>26.7</td>
<td>18.1</td>
<td>25.3</td>
<td>17.1</td>
</tr>
<tr>
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<td>14.2</td>
<td>8.1</td>
<td>11.3</td>
<td>6.4</td>
<td>3.0</td>
<td>1.7</td>
</tr>
<tr>
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<td>22.2</td>
<td>14.1</td>
<td>10.4</td>
<td>6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>4.3</td>
<td>7.4</td>
<td>2.0</td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAE</td>
<td>17.1</td>
<td>19.0</td>
<td>16.1</td>
<td>20.8</td>
<td>16.5</td>
<td>22.0</td>
</tr>
</tbody>
</table>

From Table 6-19, the average MAE is around 16 sec and the average percent difference is around 20%. The biggest difference is in time interval 5 which has a
percent difference of 68.2%. In Table 6-16, the volume of the observed group in time interval 5 is about 50% over the capacity which will take an additional amount of time to clear the intersection. As stated earlier, this over saturation delay is underestimated in CORSIM, because it takes several intervals to clear the intersection.

In general, the results show that the algorithms are robust and provide good accurate results when compared with CORSIM.

A statistical test is utilized to test the difference in travel time results obtained by using 100, 120 and 60 detector update time intervals. The statistical test results indicate that under 95% confidence level there is no significant difference among the results obtained from 100sec, 120sec, and 60 sec detector update time interval. Since there is no significant difference in the results, we recommend the use of 120 secs (2 minutes update) for its ease of real time application.