Chapter 7- Incident Situation

7.1 Introduction

This chapter covers the estimation of the travel time on arterial streets under incident conditions. The occurring time of the incident and the time it takes to clear it are known variables.

7.2 Definition of New Variables Used in Chapter 7

The following are the variables utilized in this chapter:

$Q_{mq}^t$: Number of vehicles that newly joined the incident queue during time interval $t$ on all approaching lanes.

$Q_{qQ}^t$: Cumulative number of vehicles in the incident queue at the end of time interval $t$ on all approaching lanes

$L$: Length of the link ;(ft)

$L_{TD}$: Distance from the downstream intersection to the location of the detector;(ft)

$L_i$: Distance from the downstream intersection to the location of the incident;(ft)

$D_n$: Saturation flow per lane;(veh/h/ln)

$C$: Capacity of each lane;(veh/h/ln);

$N$: Total number of lanes on this link.

$n$: Number of lanes blocked.

$CRF$: Capacity Reduction Factor for open lanes due to incident. (Assumed to be 0.7)

$t_1$: The average time of the vehicles in the observed group traveling from the end of
link to the location of the detector.

t2: Travel time from the location of the detector to the location of the incident.

t3: The stopped delay of the vehicles in the observed group due to incident.

t4: Travel time from the location of incident to the end of the queue of the intersection.

t5: Intersection control delay.

7.3 Methodology

In order to be consistent with the methodology introduced in previous chapters, the notion of observed group of vehicles is similarly adopted in the incident case. However, the vehicles in the observed group may get separated by the incident before reaching the intersection. Therefore, in calculating the intersection control delay the initial observed group may get divided into two groups. For example, 50 vehicles detected by detector in 100 seconds are regarded as the original observed group of vehicles. The incoming volume to the incident is then 50/100 (veh/sec). Let us assume that the maximum number of vehicles that can depart the incident location is only 40
vehicles in 100 seconds, since the capacity of the incident is smaller than the incoming volume. Hence, the departure volume of the incident is equal to its capacity which is 40/100 (veh/sec), which also represents the incoming volume to the intersection. As stated in Chapter 4, since the incoming vehicles during a cycle length (100 sec) are 40 vehicles in this example. These 40 vehicles are now regarded as the observed vehicle group arriving at the intersection during a cycle length of 100 secs. Their intersection control delay and their queue at the intersection in this time interval can be determined using the methodologies presented in the previous chapters. The question to be raised is how we can compute the average intersection control delay for all the vehicles in the original observed group (50 vehicles in the example).

In order to solve this problem, the average travel time for the whole observed group is divided into two parts: a) the average travel time of the observed group from the end of the link to the incident location including its over-saturation delay, and b) the average travel time from the incident location to the end of downstream intersection including the times in initial queue and in intersection control delay. These two travel times are computed independently for each updated time interval. But, they are combined and weighted by the volume in each part of the observed group to obtain the total average travel time on a link.

We have five cases for determining the average travel time on a link. They describe the different variations in queue size and location of incident as shown in Table 7-1.
Table 7-1 Cases for Incident Situation

<table>
<thead>
<tr>
<th>Case</th>
<th>Location of Incident</th>
<th>Queue of the intersection</th>
<th>Queue of the incident</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>downstream of detector</td>
<td>not reached the incident</td>
<td>not reached the detector</td>
<td></td>
</tr>
<tr>
<td>Case 2</td>
<td>downstream of detector</td>
<td>reached the incident</td>
<td>not considered</td>
<td></td>
</tr>
<tr>
<td>Case 3</td>
<td>downstream of detector</td>
<td>not reached the incident</td>
<td>reached the detector</td>
<td>blackout on detector</td>
</tr>
<tr>
<td>Case 4</td>
<td>upstream of detector</td>
<td>not reached the detector</td>
<td>not considered</td>
<td></td>
</tr>
<tr>
<td>Case 5</td>
<td>upstream of detector</td>
<td>reach the detector</td>
<td>not considered</td>
<td></td>
</tr>
</tbody>
</table>

7.3.1-Case 1:

In this case, the incident is located on the downstream side of the detector and the initial queue of the intersection doesn’t reach the incident location as shown in Figure 7-2.

![Figure 7-2 Case 1](image)

To compute the average travel time of the vehicles in the original observed group, the following steps are adopted:

Step 1: Compute the travel times $t_1$, $t_2$ and $t_3$ of the vehicles in the original observed
group detected by detector as shown in Figure 7-2 during each time interval.

Step 2: Compute the average travel time of $t_4 + t_5$ for the vehicles in the observed group which passed the incident location during each time interval.

Step 3: Compute the average travel time on the link for the same time interval based on the results obtained in steps 1 and 2.

**Step 1-Compute the Travel Time from the End of Link to the Incident Location**

**Travel time $t_1$:**

Let $t_1$ be the average time of the vehicles in the observed group traveling from the end of link to the location of the detector which can be computed as follows:

$$t_1 = \frac{L - L_{TD}}{\text{Speed}_{\text{limit}}} \text{(sec)} \quad \text{(Eq 7-1)}$$

**Travel time $t_2$:**

Let $t_2$ be travel time from the location of the detector to the location of the incident which can be computed as follows:

$$t_2 = \frac{L_{TD} - L_i - (Q_s^{-1})/N \times 19}{\text{Speed}_{\text{by detector}}/2} \text{(sec)} \quad \text{(Eq 7-2)}$$

The travelers arriving at the queue will have varying speed ranging from zero to full speed. Hence, an average speed is considered by dividing the detected speed by 2.

The length of the vehicle queue behind the incident is computed by determining the number of vehicles in the queue divided by the number of blocked lanes and times the average headway between any two vehicles which is equal to 19 ft.

**Travel time $t_3$**

Let $t_3$ be the delays caused by the initial queue behind the incident and by the over-saturation flow rate of the vehicles in the observed group at the incident location. These delays are treated similar to the stopped delays encountered at a signalized...
intersection, because the vehicles would stop behind the incident and then dissipate according to the available capacity at the incident bottleneck.

The average stopped delay of the vehicles in the observed group, as explained earlier, is the summation of the areas of A, B, and C under the curve as shown in Figures 7-3 and 7-4. Area A of Figures 7-3 and 7-4 are caused by the initial queue. The delay of the initial queue \( t_i \) that is encountered by the first vehicle in the observed vehicle group is computed by determining the number of vehicles in the queue divided by the dissipation rate at the incident location. The dissipation rate is based on the available number of open lanes adjusted for the reduction in lane capacity due to the incident. The equation is as follows:

\[
t_i = \frac{Q_{q}^{t-1}}{D_n \times CRF \times (N - n)} \times 3600 \]

(Eq 7-3)

![Figure 7-3 CL greater than ti](image)
Figure 7-4 CL less than $t_i$

From Figures 7-3 and 7-4, area $A$ is dependent on the time length of $CL$ and $t_i$. If $CL$ is greater than $t_i$, at the end of $t_i$ the queue of the observed group can be computed as $V \times N \times \frac{t_i}{3600}$ as shown in Figure 7-3. Then the queue will build up to

$$V \times N \times \frac{t_i}{3600} + \frac{CL - t_i}{CL} \times Q'_m$$

at the end of time interval $CL$. If $CL$ is less than $t_i$, the queue of the observed vehicle group will build up to $V \times N \times \frac{CL}{3600}$ during the time interval $CL$, as shown in Figure 7-4. Then the queue will remain constant from the end of $CL$ to the end of $t_i$ since all the vehicles in the observed group have already joined the queue. Therefore, according to Figures 7-3 and 7-4, the average stopped delay of the vehicles in the observed group caused by the initial queue (SP1) is the area $A$ weighted by the total incoming vehicles which can be computed from the graphs as follows:
When the first vehicle in the observed group starts to clear the incident, the queue of the observed group will continue to build up if the incoming volume is greater than the dissipating volume of the incident and \( CL \) is greater than \( t_i \). This part of the stopped delay is represented by Area B as shown in Figure 7-3. However, if \( CL \) is less than \( t_i \), the area B in Figure 7-3 doesn’t exist as shown in Figure 7-4, because none of the vehicles in the observed group has left the incident location. The area of trapezoid B can be computed as follows:

\[
SP_1 = \frac{0.5 \times V \times N \times \min(t_i, CL) \times \min(t_i, CL) \times 3600}{\text{Total number of vehicles in the observed group}} + \max(0, t_i - CL)
\]

\[
= \frac{0.5 \times V \times N \times \left(\frac{\min(t_i, CL)}{3600}\right)^2}{\text{Total number of vehicles in the observed group}} + \max(0, t_i - CL)
\]

Hence, the average stopped delay \( SP_2 \) of area B can be computed as:

\[
SP_2 = \frac{0.5 \times (V \times N \times \frac{t_i}{3600} + \max(0, V \times N \times \frac{t_i}{3600} + \frac{CL - t_i}{CL} \times Q_{mq}')) \times \max(0, CL - t_i)}{\text{Total number of vehicles in the observed group}}
\]

The last part of the stopped delay is related to the time it takes the vehicles in the observed group to dissipate through the incident bottleneck. It is represented by area C in Figure 7-3 and 7-4. In area A and B, the height of the triangle C is computed as

\[
V \times N \times \frac{\min(CL, t_i)}{3600} + \frac{\max(0, CL - t_i)}{CL} \times Q_{mq}'
\]

and the base is computed as:
Therefore the average stopped delay SP3 of triangle C can be computed as:

\[
SP3 = \frac{0.5 \times base \times height}{Total \ number \ of \ vehicles \ in \ the \ observed \ group} \times \frac{(V \times N \times \frac{\min(CL, t_i)}{3600} + \frac{\max(0, CL - t_i)}{CL} \times Q_{mq}^t)^2}{CRF \times D_a \times (N - n) \times 3600}
\] .......................................................................................(Eq 7-9)

Therefore, \( t_3 \) can be computed as the summation of the total stopped delays weighted by the number of vehicles in the observed group:

\[
t_3 = SP1 + SP2 + SP3 ...................................................................................................................(Eq 7-10)
\]

**Step 2-Compute the Intersection Control Delay and the Travel Time from Incident to Intersection.**

As stated earlier, there is no guarantee that the observed volume would remain intact in passing the incident location. The first task in this step is to compute the departure volume of the observed group past the incident location based on the volume and on the queue of the upstream location of the incident. The upstream queue for time interval \( t \) is determined using the shockwave method. The queue length is based on the cumulative queue at time interval \( t-1 \) \( (Q_{q}^{t-1}) \) plus the specific queue of the observed group \( (Q_{mq}^t) \) that joins the cumulative queue at the end of time interval \( t \).

Based on the arriving volume and the queue behind the incident, the following situations may arise as shown in Figure 7-5. If there is no initial queue at the end of time interval \( t-1 \), i.e. \( (Q_{q}^{t-1}) \) is zero, and the arriving volume \( V \) is less than the
departure capacity then the observed group would remain intact and would leave the incident location as (Vnew). However, if the arriving volume is greater than the bottleneck capacity, when there is no initial queue, a queue build up would take place that would divide the observed group into two parts. A part would leave the incident as (Vnew) and a remaining part \( Q'_{mq} \) that would become the initial queue for the next time interval. In this situation, the number of vehicles leaving the incident is equal to the number incoming vehicles during time interval CL \( (V \times CL \times N) \) minus the number of vehicles in queue established during this time interval \( Q'_{mq} \). Therefore, the new volume is computed as follows:

\[
V_{new} = \frac{V \times CL \times N - Q'_{mq}}{N \times CL} \]  
(Eq 7-11)

If the cumulative queue at the end of time interval t-1 is greater than zero \( (Q'_{q} > 0) \), as shown in Figure 7-5, the arriving observed group \( V \times CL \times N \) may be divided depending on the change in the cumulative queue behind the incident and the dissipation rate at the incident location. The change in the cumulative queue behind the incident at the end of time interval t is represented by \( Q'_{t} - Q'_{t-1} \). If \( Q'_{t} - Q'_{t-1} \) is positive, it means that the departing volume at the bottleneck is greater than the incoming volume, and if \( Q'_{t} < Q'_{t-1} \) is less than the number of departing vehicles, some of the vehicles in the observed queue will depart the incident location. Hence, the departure volume at the incident location during time interval t is computed as

\[
V_{new} = \frac{Q'_{t-1} - Q'_{t} + V \times N \times CL}{N \times CL} \]  
(Eq 7-12)

However, if the departure volume is smaller than the incoming volume, and if
If $Q_{q}^{t-1}$ is greater than the number of departing vehicles, all of the vehicles in the observed group will stay behind the incident location. In this case, the departure volume at the bottleneck ($V_{\text{new}}$) is equal to the bottleneck dissipation capacity ($V_{\text{max}}$).

It is important to remember here, that $V_{\text{new}}$ may partially represent the vehicles in the observed group. It only represents the departure volume at the bottleneck for each time interval.

![Figure 7-5 Departure Volume from Incident](image)

The departure volume ($V_{\text{new}}$) at the incident location represents the incoming volume to the intersection. The number of vehicles in the new approaching volume to the intersection is identified as $V_{\text{new}} \times CL$. Now, we can compute the intersection control delay (t5) based on the known incoming volume using the same methodology as stated in earlier chapters.

The queue build up at the intersection is consequently determined based on the approaching volume. Then, the travel time from the incident location to the initial queue of the intersection (t4) can be calculated by assuming that the vehicles would
experience the same speed as the one detected by the detector.

\[ t_4 = \frac{L_i - L_q}{\text{speed by detector}} \text{ (sec)} \] \hspace{0.5cm} \text{(Eq 7-13)}

**Step 3- Compute the average travel time on the link for the observed group based on the results obtained in steps 1 and 2.**

The main focus in this step is to determine at what time interval the observed group leaves the incident location in part or as a whole group. By doing so, it will allow us to compute the total travel times experienced by each part of the observed group, and then weight them according to the number of vehicles in each part of the observed group in order to obtain the weighted average travel time for the total observed group. To carry on this process, the following assumptions are made. Let the arrival of the first vehicle in the observed group that first arrives at the incident location, be at time \( t_0 \). Then, the first vehicle of the current observed group under consideration (\( j \)) will arrive at the incident at \( t_0 + t_i + (j \times CL) \), where \( t_i \) is the initial delay determined in step 1, and \( j \times CL \) is the time increment since \( t_0 \). The last vehicle of the observed group \( j \) will take an additional time \( \frac{Q_{mg}'}{D_n \times CRF \times (N - n)} + CL \) to dissipate through the incident location as determined in step 1. Therefore, the time the last vehicle in observed group \( j \) to leave the bottleneck is:

\[ t_0 + t_i + \frac{Q_{mg}'}{D_n \times CRF \times (N - n)} + (j + 1) \times CL \]

The time difference (TD) between the first and the last vehicle arriving at the incident location is either equal to \( CL \) or greater than \( CL \). If the first vehicle of group \( j \) arrives at the incident location at the beginning of a cycle length and TD is equal to a
cycle length then all the vehicles will leave the bottleneck during this time interval.

However, the arrival time of the first vehicle could be in the middle of a cycle length, and part of the observed group $j$ will dissipate the incident location in this time interval and the other part will dissipate in the subsequent time intervals depending on how big is $TD$ compared to $CL$.

Let $k \times CL$ represents the start time of the next time interval after the first vehicle arrives at the incident location. This point represents the division in time between parts of the observed group that can be cleared in this time interval and those that can be cleared in subsequent intervals.

Then, from the above equations, $t_0 + (k) \times CL$ should lie between:

$t_0 + t_i + (j) \times CL < t_0 + (k) \times CL \leq t_0 + t_i + \frac{Q_{mq}'}{D_n \times CRF \times (N - n)} + (j + 1) \times CL$ ...........

...............................................................................................................(Eq7-14)

Deleting $t_0$ from all equations, then $(k) \times CL$ lies between:

$t_i + (j) \times CL < (k) \times CL \leq t_i + \frac{Q_{mq}'}{D_n \times CRF \times (N - n)} + (j + 1) \times CL$ ...................(Eq7-15)

$k$ can be determined from Eq7-15, since all its variables are computed in step 1. The time difference ($TD_k$) between the arrival of the first vehicle and the start of the next cycle length is now known. The percent of vehicles that can be cleared during this time period $TD_k$ is determined as a percent of $TD_k/TD$.

Therefore, the percent of vehicles in the observed group $j$ that will be cleared the incident location in time interval $(k - 1) \times CL$ can be computed as:
Then the percent of vehicles in the original observed group that will clear the incident during time interval \(k \times CL\) is computed as follows:

\[
P_2 = 1 - P_1
\]  

(Eq 7-17)

The number of vehicles in \(P_1\) and \(P_2\) will experience different intersection control delays, because they arrive at the intersection at different times. Their intersection control delay can be computed as follows:

\[
P_1 \times (t_4 + t_5)_{(k-1)CL} + P_2 \times (t_4 + t_5)_{(k\times CL)}
\]  

(Eq 7-18)

where \(t_4\) and \(t_5\) are computed earlier in Step 2.

Therefore, the average travel time on link \(i\) is represented as:

\[
t_1 + t_2 + t_3 + P_1 \times (t_4 + t_5)_{(k-1)CL} + P_2 \times (t_4 + t_5)_{(k\times CL)}
\]  

(Eq 7-19)

If \(\frac{Q^i_{mq}}{D_n \times CRF \times n}\) is greater than \(CL\), i.e. if \((TD - TD_k)\) is greater than \(CL\), there will be some vehicles that will dissipate in another time period beyond the CL which are represented by \(P_3\). However, \(P_2\) now takes a full CL to dissipate and it is computed as follows:

\[
P_2 = \frac{CL}{D_n \times CRF \times n + CL}
\]  

(Eq 7-20)

\(P_3\) is equal to \(1 - P_1 - P_2\)

The overall control delay of the observed group can now be computed as follows:

\[
P_1 \times (t_4 + t_5)_{(k-1)CL} + P_2 \times (t_4 + t_5)_{(k\times CL)} + P_3 \times (t_4 + t_5)_{(k+1)CL}
\]  

(Eq 7-21)
7.3.2 Case 2

In this case, the incident is located on the downstream side of the detector and the initial queue at the intersection reaches the incident location as shown in Figure 7-6. Since the queue at the intersection reaches the incident location, the departure capacity of the incident is greater than the intersection capacity, \((n*Dn*CRF>N*C)\). Therefore, the incident in this case can be ignored since the delay on this link is mainly caused by low intersection capacity. Algorithm 1 in the non-incident situation is now used to estimate the average travel time of the observed group.

![Figure 7-6 Case 2](image)

7.3.3 Case 3

In this case, the incident is located on the downstream side of the detector and the queue reaches the detector causing a blackout condition.

Similar to algorithm 3 in non-incident situation, the volume on upstream link i-1 is utilized as the incoming volume. Meanwhile, the travel time estimation is conducted similar to case 2 above.

7.3.4 Case 4:

In this case, the incident is located on the upstream side of the detector as shown
The travel time in this case consists of two parts. The first part is the average travel time from the end of the link \( i \) to the location of the incident which is \( t_1 \). The second part is the average travel time from location of the incident to the intersection including the intersection control delay which is \( t_2 \).

![Figure 7-7 Case 4](image)

The dissipating volume from link \( i-1 \), as determined by algorithm 3 in the non-incident situation, is used as the incoming volume. In addition, the data from the sensor is not useful for this part of analysis. Therefore, the difference between the arriving volume and the departing volume \( V \times N - D_n \times (N - n) \) is used to estimate the queue behind the incident location. The same procedures discussed in incident condition are used to compute the travel time \( t_1 \). \( t_2 \) is computed by using the detector data and the non-incident algorithms. However, the division of the observed group into different time intervals is also possible in this situation, and the same procedures as in case 1 of incident condition are utilized.
7.4 Incident Clearance Time:

The time to clear an incident on arterial streets is usually smaller than those incidents taking place on freeways, because the incident severity is less and the accessibility to the incident is higher. We shall consider the range to clear an incident on an arterial street to lie between 10 to 45 minutes based on the incident severity. We divide this range into three categories; Level 1 incidents will be cleared between 10 and 20 minutes, while level 2 incidents will be cleared from 20 to 30 minutes and level 3 will be cleared from 30 to 45 minutes. The clearance algorithm will randomly generate the clearance time for a specific incident based on the cumulative uniform distribution of these times within a severity level. The level of severity of the incident is provided by the traffic control center as obtained from field reports.

Once the incident is cleared, the normal capacity of the road \((D_n \times N)\) is resumed and the queue behind the incident \(Q_q^i\) is dissipated at this capacity level. Cases 1, 2, 3, and 4 under incident condition are still utilized to estimate the travel time on the link as well as the queue behind the incident location \((Q_q^i)\), till the queue is totally dissipated. Once \(Q_q^i\) is equal to zero, no queue will be behind the incident location and normal traffic conditions are resumed. Here, the algorithms under no-incident condition will take over and estimate the travel times.

7.5 Application

The methodology to estimate the travel times under incident condition is applied to an arterial street network made up of three links, similar to the one used in
non-incident condition. Again, CORSIM is used to validate the results and to provide the input data to the algorithms. Let us assume that an incident took place at 632ft from the intersection stop line and blocked the middle lane of the three lane link as shown in Figure 7-8. The length of main link i is 1600ft, and the loop detector on this link is located at 1100ft from the intersection. The cycle length for this intersection is 100 secs with 60 secs of green time. The saturated departure flow rate in green time is simulated is 1800 veh/h/ln. Therefore, the intersection capacity is 1800*60/100=1080 veh/h/ln. Five time intervals with different incoming volumes are analyzed in this application. The detected speed, number of vehicles, and average dwelling time from detector are shown in Table 7-2. Assume the queue density at the incident to be 120vpmpl.

Figure 7-8 Simulation From CORSIM
<table>
<thead>
<tr>
<th>Time period</th>
<th>Detector(veh/cycle length/3 lanes) count</th>
<th>average detected speed(mph)</th>
<th>Kt(veh/mile)</th>
<th>average dwelling time(sec/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>88</td>
<td>36.8</td>
<td>28.7</td>
<td>10.3</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>37.9</td>
<td>31.6</td>
<td>10.6</td>
</tr>
<tr>
<td>3</td>
<td>101</td>
<td>37.7</td>
<td>32.2</td>
<td>10.7</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>36.5</td>
<td>24.6</td>
<td>8.9</td>
</tr>
<tr>
<td>5</td>
<td>42</td>
<td>42.1</td>
<td>12.0</td>
<td>4.57</td>
</tr>
</tbody>
</table>

**Departure Volume from Incident for each Time Interval:**

To better demonstrate the workings of the methodology, let us determine first the departure volume for each time interval.

In the first time interval, there is no initial queue behind the incident \( Q_{q-1} = 0 \).

From Table 7-2, the detected volume is \( 88/3 = 29.33 \text{ veh ln} \). These 29.33 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 36.8 mph.

The density is \( K_{td} = \frac{\text{flow}}{\text{speed}} = \frac{29.33}{100} \times \frac{3600}{36.8} = 28.7 \text{ veh/mile} \);

\( V = 29.33/100 \times 3600 = 1056 \text{ vphpl} \)

Since the capacity reduction factor in CORSIM is close to 1, let the CRF be 1 in this computation. The backward shockwave speed is:

\[
W_{d} = \frac{(D_{n} \times CRF \times (N - n) - V \times N) / N}{K_{id} - K_{td}} = \frac{(1800 \times 2 - 1056 \times 3)/3}{120 - 28.7} = 1.577
\]

The queue rate is computed as follows:

\[
QR = \frac{dn}{dt} = (V \times N - D_{n} \times (N - n) - W_{d} \times K_{id} \times N) = (1056 \times 3 - 1800 \times 2 - 1.577 \times 28.7 \times 3) = -568
\]

\( \Rightarrow Q'_{mq} = 0 \)

Therefore, the cumulative queue behind the incident is zero at the end of this time.
Similarly, the queue behind the incident for the other time interval are computed and the results are shown in Table 7-3.

Table 7-3 Queue behind Incident

<table>
<thead>
<tr>
<th>Time period</th>
<th>W</th>
<th>QR</th>
<th>Qn</th>
<th>$Q'_{mq}$</th>
<th>$Q'_q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.58</td>
<td>-568</td>
<td>-15.771</td>
<td>-15.8</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>-0.14</td>
<td>49.2</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>3.15</td>
<td>-1133</td>
<td>-31.5</td>
<td>-31.4</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>6.4</td>
<td>-2319</td>
<td>-64.4</td>
<td>-64.4</td>
<td>0</td>
</tr>
</tbody>
</table>

According to Figure 7-5, the departure volume at the bottleneck for each time interval is determined based on the detected incoming volume, the queue build up behind the incident for the observed group ($Q'_{mq}$) in time interval $t$, and the incident cumulative queue ($Q'_q$). The departure volume at the bottleneck for each time interval is shown in Table 7-4.

Table 7-4 Departure Volume at Incident

<table>
<thead>
<tr>
<th>Time period</th>
<th>$Q'_{mq}$</th>
<th>$Q'_q$</th>
<th>Incoming volume behind incident(vph)</th>
<th>Departure volume at incident(vph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-15.8</td>
<td>0</td>
<td>1056</td>
<td>1056</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>3</td>
<td>1.4</td>
<td>1.4</td>
<td>1212</td>
<td>1162.8</td>
</tr>
<tr>
<td>4</td>
<td>-31.5</td>
<td>0</td>
<td>900</td>
<td>949.2</td>
</tr>
<tr>
<td>5</td>
<td>-64.4</td>
<td>0</td>
<td>504</td>
<td>504</td>
</tr>
</tbody>
</table>
Step 1-Compute the Travel Time from the End of Link to the Incident Location

In time interval 1, the incoming volume is 1056 vph, and $Q'_m$ and $Q'_q$ are zero as shown in Table 7-4.

From Eq 7-1, $t_1 = \frac{L - L_{TD}}{\text{Speed}_{\text{limit}}} = \frac{1600 - 1100}{45 \times 5280 / 3600} = 7.6 \text{ sec}$

From Eq 7-2, $t_2 = \frac{L_{TD} - L_i - (Q^{-1}_q) / 3 \times 19}{\text{Speed by detector} / 2} = \frac{1100 - 632 - 0}{36.8 \times 5280 / 3600} = 17.3 \text{ sec}$

From Eq 7-4 to 7-9

$SP_1 = SP_2 = SP_3 = 0$

Therefore, from Eq 7-10, $t_3$ in time interval 1 is equal to zero

$t_1$, $t_2$ and $t_3$ for other time intervals are computed similar to time interval 1 and the results are shown in Table 7-5

<table>
<thead>
<tr>
<th>Time period</th>
<th>$t_1$(sec)</th>
<th>$t_2$(sec)</th>
<th>$t_3$(sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.6</td>
<td>17.3</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>7.6</td>
<td>16.8</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>7.6</td>
<td>16.6</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>7.6</td>
<td>17.5</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>7.6</td>
<td>15.1</td>
<td>0</td>
</tr>
</tbody>
</table>

Step 2-Compute the Intersection Control Delay and Travel Time from Incident to Intersection.

In time interval 1, the incoming volume at the intersection is 1056 vph according to Table 7-4. The intersection control delay is computed based on algorithms developed for the non-incident case as presented in earlier chapters. The computations are as follows:
\[ h_1 = \frac{100}{29.33} = 3.41 \text{ sec/veh} \]

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

\[ S_1 = 36.8 \text{ mph}, S_2 = 6.5 \text{ mph} \]

\[ t = \frac{S_1 \times h_1 - 19}{(S_1 - S_2)} = \frac{36.8 \times 3.41 - 19}{36.8 - 6.5} = 3.51; \]

\[ h_3 = \frac{t \times h_2}{t - h_2} = \frac{3.51 \times 2}{3.51 - 2} = 4.64 \text{ sec/veh} \]

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

\[ d_1 = \frac{0.5 \times Q_{\text{max}} \times Q_{\text{arrival}}}{\text{Total} \_ \text{arrival}} = \frac{0.5 \times \frac{40}{3.41} \times (\frac{40}{3.41} \times 4.64 + 40)}{29.33} = 19 \text{ sec/veh}; \]

The over-saturation delay is zero since \( V \) is smaller than the intersection capacity \( d_2 = 0; \)

\( d_4 \) is equal to zero since there is no initial queue in this interval.

Hence, the intersection control delay of this time interval \( t_5 \) is 18.89 sec/veh., and the initial queue for the next time interval is zero as shown in Table 7-4.

\[ \text{From Eq 7-8} \quad t_4 = \frac{L_i - L_q}{\text{speed} \_ \text{by detector}} = \frac{632 - 0}{36.8 \times 5280/3600} = 11.7 \text{ (sec)} \]

The intersection control delay for the other time intervals is computed similar to time interval 1 and the results are shown in Table 7-6.
Table 7-6 Travel time \( t_4 \) and Intersection Control Delay

<table>
<thead>
<tr>
<th>Time period</th>
<th>( t_4 ) (sec)</th>
<th>Intersection Control Delay ( t_5 ) (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.7</td>
<td>18.9</td>
</tr>
<tr>
<td>2</td>
<td>11.0</td>
<td>26.9</td>
</tr>
<tr>
<td>3</td>
<td>10.6</td>
<td>33.0</td>
</tr>
<tr>
<td>4</td>
<td>11.6</td>
<td>30.1</td>
</tr>
<tr>
<td>5</td>
<td>10.2</td>
<td>19.9</td>
</tr>
</tbody>
</table>

**Step 3- Compute the average travel time on the link for the same time interval based on the results obtained in steps 1 and 2.**

Since the values of \( Q^{r-1}_q \) and \( Q'_m \) are obtained, the k value, as well as P1 and P2 are determined by Eq 7-15, 7-16 and 7-17 respectively.

In time interval 3, the \( Q^{r-1}_q \) is equal to zero and \( Q'_m \) is equal to 1.37 as shown in Table 7-4. It is the time interval that has a queue. From Equation 7-15,

\[
t_i + (j) \times CL < (k) \times CL \leq t_i + \frac{Q'_m}{D_n \times CRF \times (N - n)} + (j + 1) \times CL
\]

\[
\Rightarrow (3) \times 100 < (k) \times 100 \leq \frac{1.37}{1800 \times 1 \times 2} \times 3600 + (3 + 1) \times 100
\]

\[
\Rightarrow k = 4
\]

From Equation 7-16

\[
P_1 = \frac{k \times CL - (t_i + (j) \times CL)}{Q'_m / D_n \times n + CL} = \frac{4 \times 100 - 3 \times 100}{1.36 \times 3600 / 2 + 100} = 0.987
\]

From Eq 7-17

\[
P_1 = 1 - P_1 = 1 - 0.987 = 0.013
\]

The final intersection delay for time interval 3 is computed using Equation 7-18 as follows:
\[ P_1 \times (t_4 + t_5)_{(k-1)CL} + P_2 \times (t_4 + t_5)_{(k)CL} \]
\[ = 0.987 \times (t_4 + t_5)_{300} + 0.013 \times (t_4 + t_5)_{400} \]
\[ = 0.987 \times (9.3 + 33) + 0.013 \times (11.9 + 30.1) \]
\[ = 43.6 \text{(sec)} \]

Similarly, the travel times t4 and t5 for each observed group are computed and the results are shown in Table 7-7.

### Table 7-7 Travel time t4 and Intersection Control Delay after weighting

<table>
<thead>
<tr>
<th>Time period</th>
<th>t4+t5 after weighting (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30.6</td>
</tr>
<tr>
<td>2</td>
<td>37.2</td>
</tr>
<tr>
<td>3</td>
<td>43.6</td>
</tr>
<tr>
<td>4</td>
<td>41.1</td>
</tr>
<tr>
<td>5</td>
<td>30.1</td>
</tr>
</tbody>
</table>

The total travel time on this link under incident conditions is the summation of \( t_1 + t_2 + t_3 + t_4 + t_5 \). results are shown in Table 7-8.

### Table 7-8 Travel time on link

<table>
<thead>
<tr>
<th>Time period</th>
<th>t1+t2+t3+t4+t5 (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55.5</td>
</tr>
<tr>
<td>2</td>
<td>62.3</td>
</tr>
<tr>
<td>3</td>
<td>68.5</td>
</tr>
<tr>
<td>4</td>
<td>67.3</td>
</tr>
<tr>
<td>5</td>
<td>52.9</td>
</tr>
</tbody>
</table>

### 7.6 Comparison of Results with CORSIM

As discussed in previous chapters, the output of CORSIM shows the average travel time of all vehicles on the link during an observed time interval. However, our algorithms focus on determining the average travel time experienced only by the vehicles in the observed group. In addition, in the incident case the observed group may be subdivided which is not tracked in CORSIMS output.
Overall, it is difficult to adjust the results of CORSIM and compare them with the results of the algorithm under an incident condition. However, we can use the output of CORSIM to check whether the results of our algorithm are reasonable under a low incoming volume condition. In a low incoming volume condition, the vehicles in the observed group occupy a high proportion of the number of vehicles traveling on the link during a time interval. Since, the output of CORSIM represents all the vehicles on the link and the observed group accounts for the majority of the vehicles in a low incoming volume, the accuracy of the comparison could be justified.

The Mean Absolute Error is used to compare the fitness of the algorithm results with CORSIM results. The MAE and the average percent of difference are shown in Table 7-9

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Travel time by CORSIM(sec)</th>
<th>Travel time by Algorithm(sec)</th>
<th>Difference</th>
<th>% of difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59.0</td>
<td>55.5</td>
<td>3.4</td>
<td>5.8</td>
</tr>
<tr>
<td>2</td>
<td>57.1</td>
<td>62.3</td>
<td>5.2</td>
<td>9.1</td>
</tr>
<tr>
<td>3</td>
<td>55.4</td>
<td>68.5</td>
<td>13.1</td>
<td>23.6</td>
</tr>
<tr>
<td>4</td>
<td>61.3</td>
<td>67.3</td>
<td>6.0</td>
<td>9.9</td>
</tr>
<tr>
<td>5</td>
<td>62.3</td>
<td>52.9</td>
<td>9.5</td>
<td>15.2</td>
</tr>
<tr>
<td>MAE</td>
<td></td>
<td></td>
<td>7.5</td>
<td>12.7</td>
</tr>
</tbody>
</table>

The average MAE is around 7.5 seconds and the average percent difference is around 12.7%. In general, the statistics show that the algorithms are robust and provide good accurate results when compared with CORSIM. However, it is recommended that real world data be used in testing the accuracy of these algorithms under various traffic conditions.