

## Chapter 5- The Algorithms

### 5.1 Overall structure of the approach

The main structure of the overall approach has four built-in algorithms, as shown in Figure 5 -1. They are applied to cover the following traffic situations:

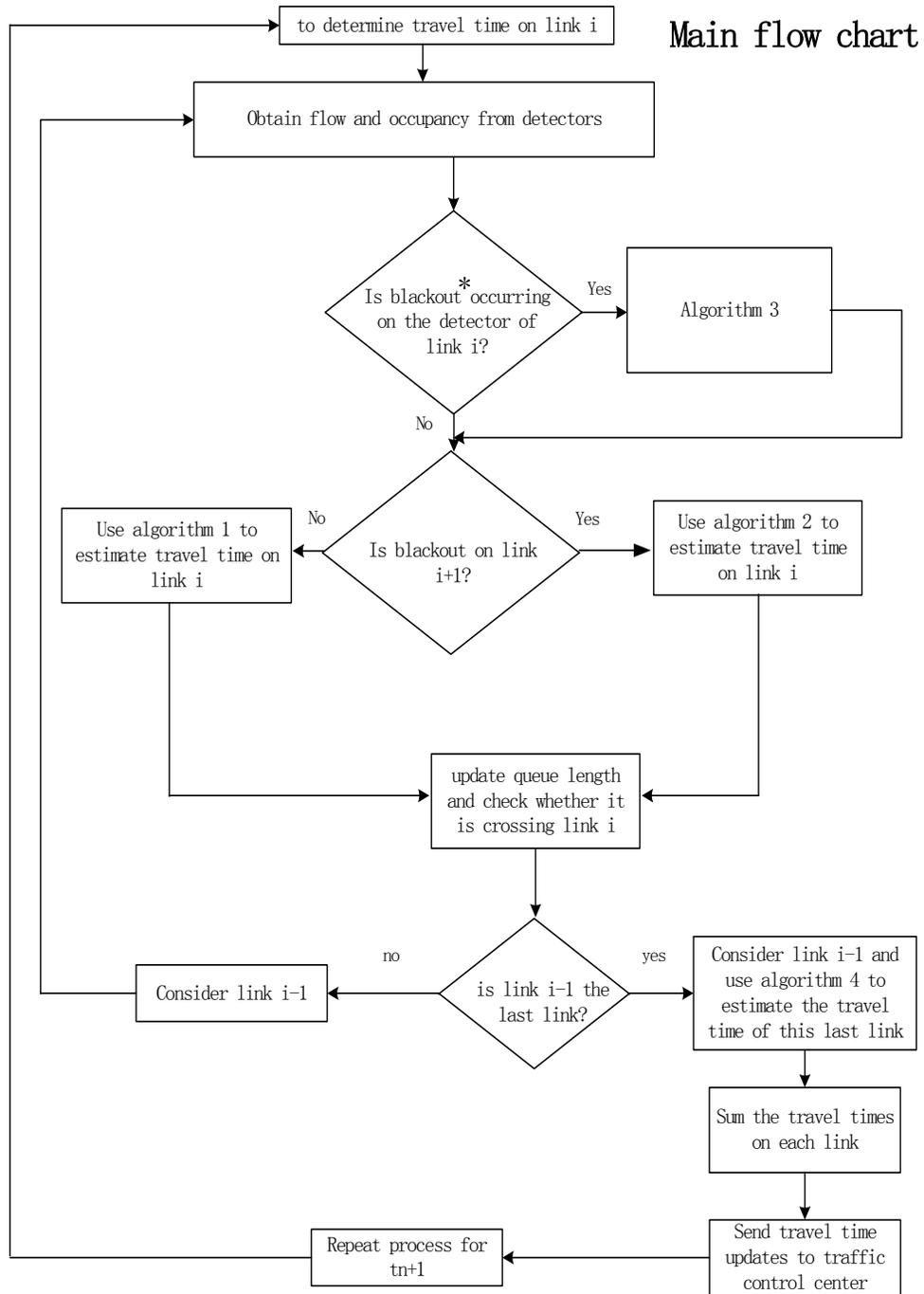
Algorithm 1: There is no bottleneck at the intersection.

Algorithm 2: There is a bottleneck at the intersection which is caused by a traffic jam in the downstream link.

Algorithm 3: There is traffic jam on link  $i$  and there is a blackout on the detector in the observed time interval.

Algorithm 4: Algorithm for a link  $i$  without an upstream link. Link  $i$  is the end link.

To start these algorithms we check whether there is a blackout on link  $i$ . If yes, we use algorithm 3. If no, we can use algorithm 1 if the traffic situation has no or else algorithm 2 is used to cover the bottleneck traffic situation caused by link  $i+1$ .



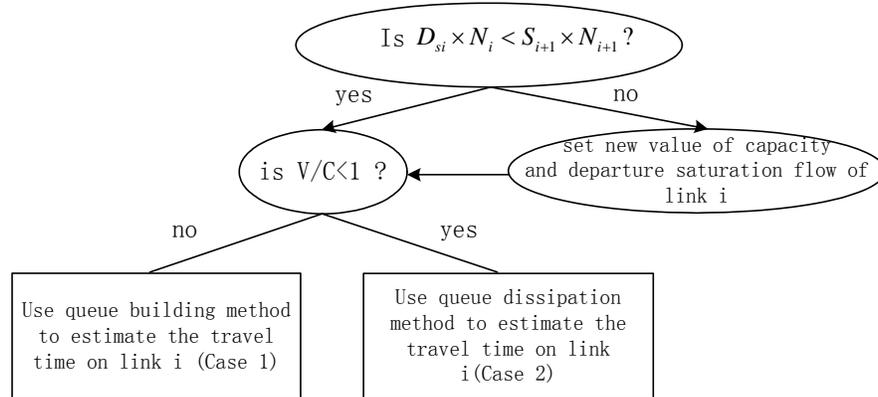
\* blackout condition exists if a car stays over the loop detector for an extended period of time

Figure 5 - 1- Main flow chart

## 5.2 . Methodology

### 5.2.1 Condition A—Algorithm 1:

Condition A applies when there is a normal traffic situation. That is, when there is no blackout on the loop detector and there is no bottleneck at the intersection. The flow chart of the algorithm is shown in Figure 5 - 2- Algorithm 1 flow chart.



Where

V: traffic volume detected at link i;

C: capacity of the intersection.

$D_{si}$  :Departure flow in green time in link i(veh/h/ln)

$S_{i+1}$  :saturation flow on downstream link i+1(veh/h/ln)

N: number of lanes

Figure 5 - 2- Algorithm 1 flow chart

$D_{si} \times N_i$  is the maximum departure volume during the green time on link i, and  $S_{i+1} \times N_{i+1}$  is the maximum acceptable volume by the downstream link i+1. A lane drop or a lane closure on link i+1 will cause the total maximum departure volume on link i to be greater than the maximum total acceptable volume on link i+1. In this case, we should reset the maximum departure flow rate on link i to be

$$D_{si} = \frac{S_{i+1} \times N_{i+1}}{N_i} \text{ (veh/h/ln), .....(Eq 5 - 1)}$$

Then, from equation 1-7 and Equation 3-1, the new capacity of link i is

$$C = \frac{S_{i+1} \times N_{i+1}}{N_i} \times \frac{g}{CL} \dots\dots\dots(\text{Eq 5 - 2})$$

Algorithm 1 represents two traffic conditions with two cases. If V/C is greater than 1, use case 2 to determine the queue length, otherwise use case 1. These cases only affect the determination of the initial delay d1 which is based on the queue situation at the intersection as dictated by the previous time steps.

● **Case 1:**

Case 1 is the queue build up case when V>C. The travel time and the queue length are estimated by the following concepts and steps:

**Initial delay d3 for the first vehicle in the observed group:**

The initial queue for this observed group can be estimated by the previous time period t-1 which is  $Q_{t-1}$

$$\text{When } (n-1) \times g \leq \frac{Q_{t-1}}{D_{si}} \leq n \times g ,$$

From equation 2-9, the average initial delay (d3) for this observed group is

$$d3 = \frac{Q_{t-1}}{D_{si}} + (n) \times red\_time .$$

**Initial queue  $Q_{t-1}$  obtained from the previous time interval:**

In case 1, where V>C; the backward forming shock-wave velocity upstream of intersection is determined in (mph).

$$W_u = \frac{V - C}{k_{td} - k_q} ;$$

The queuing rate QR(veh/h) is:

$$QR = \frac{dn}{dt} = (V - C - W_u \times k_{dr}) ;$$

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

$$Q_m = QR \times CL$$

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

The uniform stopped delay and the over-saturation are computed based on the approaching volume and the initial delay  $d_3$ , as explained earlier in Chapter 4.

Equation 3-10 in Chapter 3 is used to compute the average travel time on the link.

- **Case 2:**

Case 2 takes place when  $V < C$ . It is the queue dissipation case. The same steps are executed to obtain travel times for the queue dissipation phase, except that the shockwave now moves forward. Thus, we use a different equation to estimate the queue length as following:

$$W_d = \frac{C - V}{k_q - k_{dt}}$$

The queuing rate QR (veh/h) is:

$$QR = \frac{dn}{dt} = (V - C - W_d \times k_{dt});$$

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

$$Q_m = QR \times CL$$

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

Uniform stopped delay  $d_1$  and Over-saturation  $d_2$

The uniform stopped delay and the over-saturation delay are computed based on the approaching volume and the initial delay  $d_3$ , as explained earlier in Chapter 4.

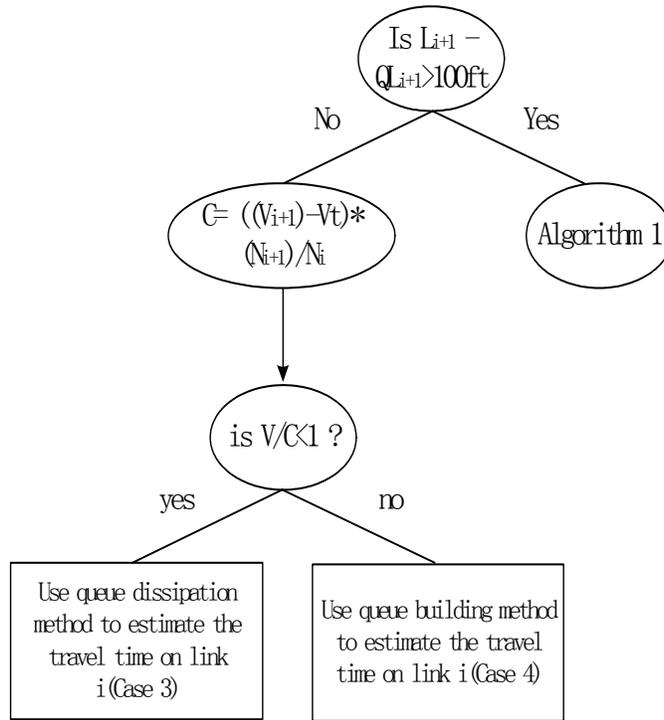
Equation 1-10 in Chapter one is used to compute the average travel time on the link.

### **5.2.2 Condition B—Algorithm 2**

In this algorithm, there may be a bottleneck at the intersection which is caused by a traffic jam at the downstream link  $i+1$ . If the bottleneck exists, the volume detected by the detector at link  $i+1$  minus the volume of turning vehicles ( $V_{turn}$  as discussed and computed earlier) represents the maximum departure volume of link  $i$ .

In this condition, the volume detected by the loop detector on link  $i+1$  is close to the actual capacity of this link particularly if the queue extends to within 100 feet of the end of this link. Figure 5 -3 displays the flow chart of this algorithm.

### Algorithm 2:



Where

$V_{i+1}$ : the volume detected at link  $i+1$ ;

$V_t$ : The turning on volume on this link minus the turning out volume on this link of this intersection

$S_{i+1}$ : Acceptable flow on link  $i+1$

$L_{i+1}$ : Length of Link  $i+1$  in (ft).

$Q_{i+1}$ : Length of vehicle queue in (ft).

Figure 5 - 3- Flow chart of Algorithm 2

The most important mission of algorithm 2 is to reset the capacity of link  $i$  based on the conditions of link  $i+1$ . Once the capacity of link  $i$  is reset, the estimation of travel time on link  $i$  is carried in the same way as in algorithm 1. The actual capacity of link  $i$  in this condition is  $C = V_{i+1} - V_{turn}$ . Where  $V_{i+1}$  is the volume detected by loop detector of link  $i+1$ , and  $V_{turn}$  is the turning movement flow.

The delay and queue estimation for case 3 and case 4 are the same as in case 1 and 2 except for the new estimation of link  $i$  capacity. Thus, the same steps are

executed to obtain the travel times and the queue length for case 3 as in case1, and case 4 as in case 2 except for the new capacity of link i.

### 5.2.3 Condition C—Algorithm 3

Condition C takes place when there is blackouts at the loop detector of link i. In this condition, the data detected by the loop detector can not show the right incoming volume. Thus, we use the volume detected by its upstream link (link i-1) compared to the capacity of the upstream intersection  $C_{i-1}$  as the incoming volume and the associated observed group of vehicles.

Let us assume that the queue length on link i do not reach the end of the link, and it is greater than 100 feet away from it. Let the volume detected by the upstream link is  $V_{i-1}$ , the initial queue at link i-1 is  $Q_{i-1}$ , and the capacity of the upstream intersection is  $C_{i-1}$ . When  $V_{i-1} + Q_{i-1}$  is greater than  $C_{i-1}$  which means the volume is greater than the intersection capacity, then the maximum dissipated volume of link i-1 is  $C_{i-1}$  instead of  $V_{i-1} + Q_{i-1}$ . Thus in this case, let  $V_{i-1} = C_{i-1}$ , and this  $V_{i-1}$  represents the dissipating volume from the upstream link i-1 as shown in Figure 5 -4. But the incoming volume to link i is  $(V_{i-1} + Q_{i-1}) * (1 + t\%)$ , where  $t\%$  is the percent of accumulated volume from the turning movements at an intersection as explained earlier.

Then, if  $(V_{i-1} + Q_{i-1}) * N_{i-1} < D_{si} * (g_{i-1} / CL_{i-1}) * N_i$ , which means that the total saturation flow-restrained volume for link i is greater than the total incoming volume from link i-1 during the green time, put  $V_i = (V_{i-1} + Q_{i-1}) * (1 + t\%) * N_{i-1} / N_i$ , Where  $V_i$  represents the incoming volume for link i.

When the incoming volume to link i is greater than the saturation flow–restrained

volume for link i volume, which is  $(V_{i-1} + Q_{i-1}) \cdot N_{i-1} < D_{si} \cdot (g_{i-1} / CL_{i-1}) \cdot N_i$ , then let the incoming volume and observed group be represented by the maximum acceptable flow rate during the green time interval of upstream intersection which is

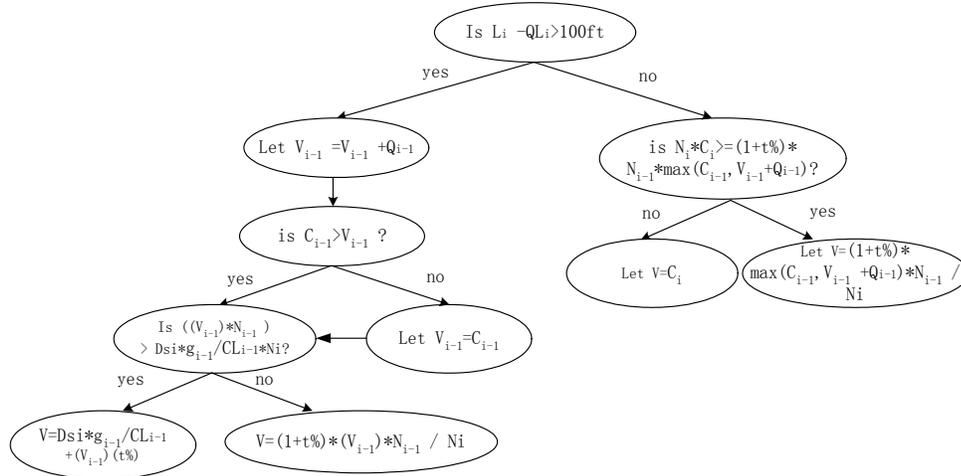
$$D_{si} \times \frac{g_{i-1}}{CL_{i-1}} + (t\%) \times V_{i-1} \quad (\text{veh.h/ln}).$$

In case that the queue length in link i is within 100 feet of the end of link i, then the incoming volume to link i can not be greater than the discharge volume of link i, which is  $C_i$ . So if  $N_i \cdot C_i$  is greater than  $N_{i-1} \cdot \max(C_{i-1}, V_{i-1} + Q_{i-1}) \cdot (1+t\%)$ ,  $\max(C_{i-1}, V_{i-1} + Q_{i-1}) \cdot (1+t\%) \cdot N_{i-1} / N_i$  prevails or else the incoming volume should be equal to  $C_i$  which is equal to the detected volume from detector in this case.

Having determined the new observed group and the incoming volume for algorithm 3, then we can continue to use algorithm 1 and 2 to estimate the intersection delays and the travel time on link i.

Since we do not have the right density data on the loop detector, we can not use the shockwave method to estimate the queue length. The alternative method to estimate the change in queue length is to use  $(V-C) \cdot CL$ . If  $V$  is greater than  $C$ , it is a queue building case; otherwise, it is a queue dissipation case.

Algorithm 3: Blackout on the loop detector in link i



Where

$V$ : incoming volume for link  $i$ ;

$Q_{i-1}$ : Initial queue for link  $i-1$ ;

$C$ : capacity of the intersection of link  $i$ ;

$V_{i-1}$ : traffic volume detected in upstream link  $i-1$ ;

$C_{i-1}$ : capacity of the intersection of link  $i-1$ ;

$t\%$ : Percentage of number of vehicles changes of this intersection in the arterial street

$D_{si}$ : Departure flow in green time in link  $i$  (veh/h/ln);

$S_{i+1}$ : saturation flow on downstream link  $i+1$  (veh/h/ln);

$N_i$ : number of lanes of link  $i$ ;

$N_{i-1}$ : number of lanes of upstream link  $i-1$ .

Figure 5 - 4- Flow chart of Algorithm 3

#### 5.2.4 Condition D—Algorithm 4

Algorithm 4 is applied in the situation when the observed link  $i$  is the end link.

That is, it does not have an upstream link. When there is a blackout on link  $i$ , we can not utilize algorithm 3 to estimate the incoming volume since there is no upstream link. Thus, we assume the maximum travel time on this link where there is a blackout

situation. The maximum travel time is computed as  $\frac{L_i}{19} \div C$  + uniform delay +

over-saturation delay, where  $L_i$  is the length of the link  $i$ , (ft) and 19 is the average

length of the car plus the jam headway in (ft). Figure 5 -5 shows the flow chart of this

algorithm

### Algorithm 4

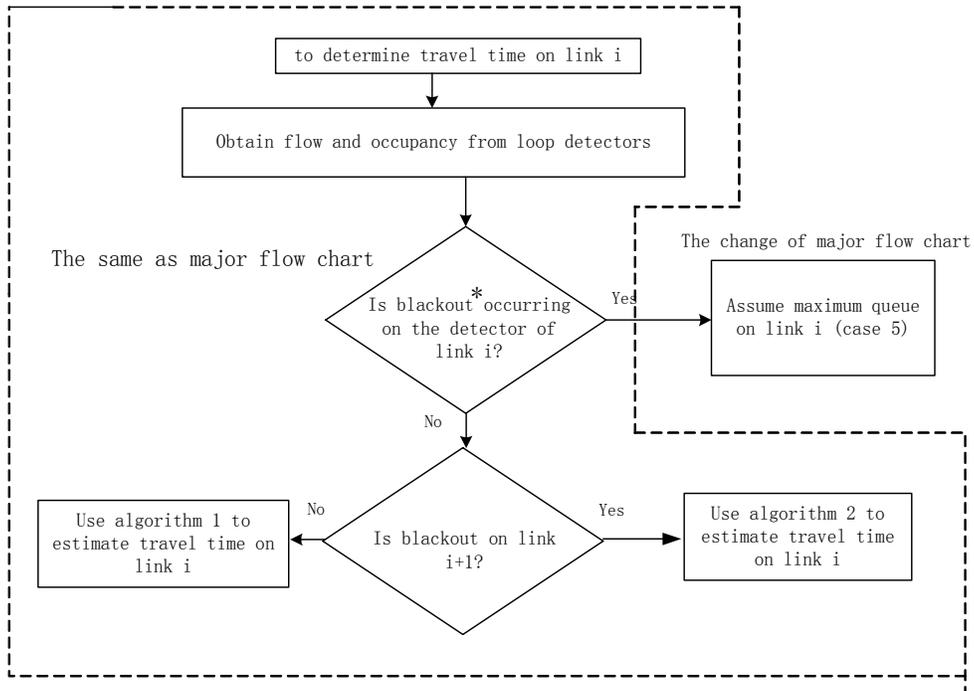


Figure 5 - 5- Flow chart of algorithm 4