A SYSTEM FOR TRAVEL TIME ESTIMATION ON URBAN FREEWAYS

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ABSTRACT

Travel time information is important for Advanced Traveler Information Systems (ATIS) applications. People traveling on urban freeways are interested in knowing how long it will take them to reach their destinations, particularly under congested conditions. Though many advances have been made in the field of traffic engineering and ITS applications, there is a lack of practical travel time estimation procedures for ATIS applications.

Automatic Vehicle Identification (AVI) and Geographic Information System (GPS) technologies can be used to directly estimate travel times, but they are not yet economically viable and not widely deployed in urban areas. Hence, data from loop detectors or other point estimators of traffic flow variables are predominantly used for travel time estimation. Most point detectors can provide this data efficiently. Some attempts have been made in the past to estimate travel times from point estimates of traffic variables, but they are not comprehensive and are valid for only particular cases of freeway conditions. Moreover, most of these methods are statistical and thus limited to the type of situations for which they were developed and are not of much general use.

The purpose of current research is to develop a comprehensive system for travel time estimation on urban freeways for ATIS applications. The system is based on point estimates of traffic variables obtained from detectors. The output required from the detectors is flow and occupancy aggregated for a short time interval of 5 minutes. The system for travel time estimation is based on the traffic flow theory rather than statistical methods. The travel times calculated using this system are compared with the results of FHWA simulation package TSIS 5.0 and the estimation system is found to give reasonable and comparable results when compared with TSIS results.

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Travel time information is important for Advanced Traveler Information Systems (ATIS) applications. People traveling on urban freeways are interested in knowing how long it will take them to reach their destinations, particularly under congested conditions. Though many advances have been made in the field of traffic engineering and ITS applications, there is a certain lack of travel time estimation procedures for ATIS applications.

Automatic Vehicle Identification (AVI) and Geographic Information System (GPS) technologies can be used to directly estimate travel times, but they are not yet economically viable and not widely deployed in urban areas. Hence, data from loop detectors or other point estimators of traffic flow variables are predominantly used for travel time estimation. Most point detectors can provide this data efficiently. Some attempts have been made in the past to estimate travel times from point estimates of traffic variables, but they are not comprehensive and are valid for only particular cases of freeway conditions. Moreover, most of these methods are statistical and thus limited to the type of situations for which they were developed and are not of much general use.

The purpose of current research is to develop a comprehensive system for travel time estimation on urban freeways for ATIS applications. The system is based on point estimates of traffic variables obtained from detectors. The output required from the detectors is flow and occupancy aggregated for a time interval of 5 minutes. The system for travel time estimation is based on the traffic flow theory rather than statistical methods. Most surveillance technologies are limited to only providing point measurements such as flow and roadway occupancy (Table 1.1: Summary of Advanced Surveillance Technologies). Other technologies that give more information are relatively costly.

1.2 PROBLEM STATEMENT

With the availability of advanced communication and electronics technologies it is now possible and more necessary than ever to develop methods for travel time estimation on urban freeways. The method developed should have general applicability for all conditions and should not be highly data hungry. It should be economically viable and at the same time accurate to be of practical use. The basis for this system should be traffic flow theory rather than statistical method. There is a clear scarcity of such comprehensive systems for travel time estimation. In light of this situation the objectives of this research are defined.

1.3 OBJECTIVES OF THE RESEARCH

The main objective of this research is to develop a comprehensive system for travel time estimation on urban freeways based on integration of traffic flow theories and advanced surveillance technologies. The system should be economically viable and applicable in real time traffic conditions. The only data needed from the surveillance systems should be flow and occupancy aggregated over reasonably short intervals of time (5 minutes). The system should work under free flow conditions, congested conditions, work zones, and under incidents.

1.4 RESEARCH TASKS

1. Complete literature review of travel time estimation techniques with identification of deficiencies.
2. Development of a travel time estimation system suitable for real time application on urban freeways
3. Validation of the system with simulation

1.5 ORGANIZATION OF THE THESIS

Chapter 2 presents literature review on traffic flow theories, travel time estimation methods, incident characteristics and their effects on travel time. The theory of shockwaves on freeways and their application to travel time estimation is presented here. The existing incident duration estimation techniques are reviewed. Chapter 3 presents the development of the travel time estimation system. Procedures for travel time estimation under free flow conditions, congested conditions, lane closures, incident conditions and all relevant cases are presented. The input data required is flows and occupancies aggregated at 5 minute level. Additional data is required only under incident conditions to establish the nature and extent of the incident. Chapter 4 presents the validation of the system with simulation data**.** Chapter 5 concludes the research with conclusions and recommendations for further research.

Technology	Flow	Roadway Occupancy/Density	Queue Length	Vehicle Classification	Spot Speed
Ultrasonics	Yes	Yes	Yes		
Active Infrared	Yes	Yes		Yes	Yes
Passive Infrared	Yes	Yes			
Microwave Radar	Yes	Yes			Yes
Acoustics	Yes	Yes		Yes	
Video Image Processing	Yes	Yes			Yes
Aerial video image processing	Yes	Yes	Yes		
Inductive Loops	Yes	Yes			Yes
Global Positioning System					
Automatic Vehicle Identification	Yes			Yes	

TABLE 1.1: Summary of Advanced Surveillance Technologies

(Source: Nam and Drew, 1995)

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

The estimation of travel times in urban freeways is a necessary step for the evaluation of performance of the freeway facilities and for Advanced Traveler Information Systems applications. Traditional methods of travel time estimation such as use of link capacity functions deduce travel times from relating traffic variables and the static capacity of the road. They do not appropriately represent the dynamic characteristics of flow. With the advent of Intelligent Transportation Systems (ITS) it is required that the estimation be performed in real-time with more accuracy and reliability than before. The reliable and efficient estimation of travel times is pivotal to the success of ITS (Nam and Drew, 1995). In order to reliably estimate travel times it is necessary to properly model traffic behavior.

The past fifty years have seen a tremendous increase in use of automobiles and expansion of highway system. There was also a surge in the study of traffic characteristics and in the development of traffic flow theories, during this period. Traffic flow is a comprehensive phenomenon of interactions among the driver, the vehicle and the road, which constantly changes over space and time. Theoretical developments were based on a variety of approaches, such as car-following, traffic wave theory (hydrodynamic analogy), and queuing theory. The nature of traffic is described by three fundamental traffic variables- flow, density and speed at the macroscopic level. Flow is defined as the number of vehicles passing a point during a specific period of time. It is the easiest traffic variable to measure. Density is the number of vehicles per unit length of a road. It is difficult to measure and hence is usually substituted with roadway occupancy, which can be measured from presence type detectors. Roadway Occupancy is the ratio of presence-type detector's occupied time to the total observation time. Density can be obtained from occupancy by means of the following expression (May, 1990):

$$k = \frac{52.8}{L_V + L_D}(\%occ) \qquad (2.1.1)$$

where,

L_V is the length of the vehicle in consideration,

L_D is the length of detection zone in the presence type detector,

%occ is the occupancy reading from the detector.

Accurate and reliable information about flow, density and speed are necessary to manage and control traffic demand and flow in real time. The different surveillance technologies and their measurements were presented in Table 1.1 in Chapter 1. It was also noted that most surveillance technologies are, however, limited to only providing point measurements such as flow and roadway occupancy. It follows that in order to estimate travel times reliably and efficiently it is necessary to develop methodologies that are based on flow and occupancy measurements.

2.2 TRAVEL TIME ESTIMATION TECHNIQUES

Conventional methods for travel time estimation use link capacity functions. Link capacity functions mathematically relate link travel time to traffic variables on the link. Link capacity functions are formulated in two ways – empirical approach and theoretical approach. In the empirical approach, empirical data is observed and mathematical functions that give best fit are proposed. In the theoretical approach, link capacity functions are developed based on theoretical methods, such as queuing theory. Two famous link capacity functions based on empirical approach are the Toronto function and the BPR function. Example of theoretical link capacity function is Davidson function. (Branston, 1976) These methods do not, however, have real time applicability.

In recent times, new attempts were made to estimate travel times based on flow measurements directly for ITS implementation. The cross correlation technique (Dailey, 1993) is an example of such methods. This method however, is statistical and does not work well under congested traffic. Lindveld et al (1999) mention that under absence of congested conditions, travel time $t_i(k)$ on a road section 'i' during time interval k can be estimated with good accuracy using the relationship

$$t_i(k) = \frac{1}{2}\left[\frac{L_i}{v_{A,k}} + \frac{L_i}{v_{B,k}}\right] \tag{2.2.1}$$

where $v_{A,k}$ and $v_{B,k}$ are the time-mean speeds at section ends A and B, respectively, during time interval k, and for section length L_i. This assumption behind this estimate is that traffic conditions (speed, flow and density) remain stationary during the time period k and are homogenous across the section. The accuracy of this method depends on length of period k and length of section L_i.

Nam and Drew (1995) provided methods for estimation of travel times under normal traffic conditions and under congested conditions using traffic dynamics. In case traffic demand exceeds capacity when there are lane closures or incidents, statistical methods are no longer applicable. It is necessary to understand the dynamics of traffic near lane closures and incidents to accurately estimate travel times. Nam and Drew (1995) also provided an analysis of traffic conditions near incidents and bottlenecks using the theory of shockwaves. Lawson, Lovell and Daganzo (1998) used Input-Output diagrams to analyze traffic upstream of a bottleneck. A discussion of these systems is provided now.

2.2.1 TRAFFIC DYNAMICS METHOD (NAM AND DREW (1995))

A typical link of length ‘x’, with two detectors located at both ends x_1 and x_2, as shown in Figure 2.2.1.1, is considered. The flow rates, $q(x_1,t)$ and $q(x_2,t)$ are measured at upstream location x_1 and downstream location x_2. They are regularly aggregated at the interval Δt at the detector locations, such that

$$\frac{x}{u_f} \leq \Delta t \leq 5\text{-}10\text{min} \qquad (2.2.1.1)$$

where u_f is the free flow speed on the link. The density of the traffic on this link at any time ‘t’ is represented by k(t).

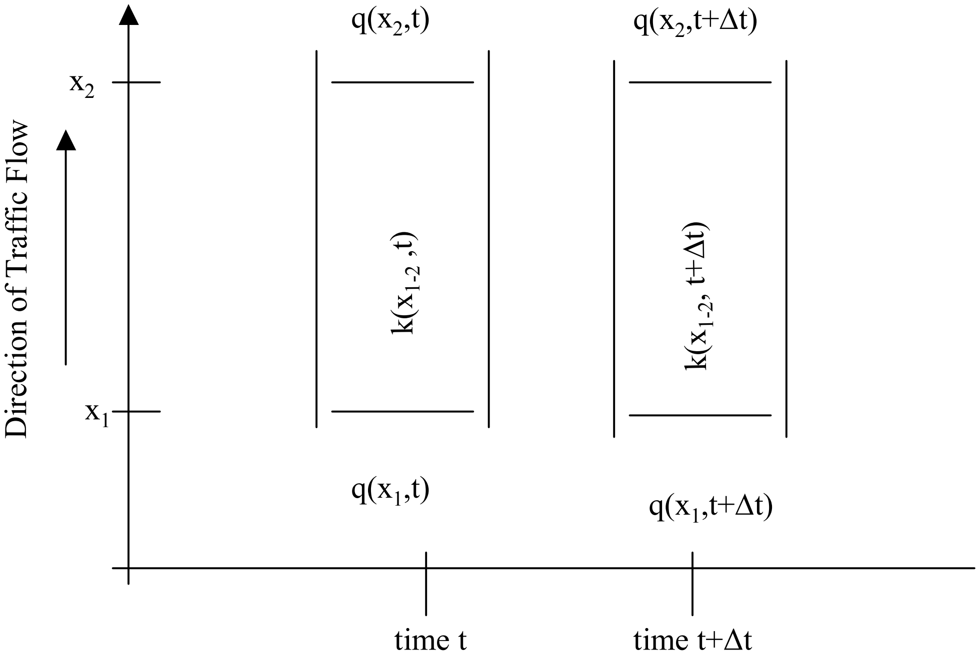


Figure 2.2.1.1: Generalized traffic conditions of a segment of freeway with two detectors at both ends x1 and x2

(Source: Nam and Drew, 1995)

The cumulative flows $Q(x_1,t)$ and $Q(x_2,t)$ are calculated now. The cumulative number of vehicles entering the link from time t_0 to t_n is

$$
\begin{aligned}
Q(x_1,t_n) &= q(x_1,t_0) + q(x_1,t_0 + \Delta t) + q(x_1,t_0 + 2\Delta t)+\ldots \\
&= q(x_1,t_0) + q(x_1,t_1) + q(x_1,t_2)+\ldots \\
&= \sum_{i=0}^{n} q(x_1,t_i)
\end{aligned}
$$

Similarly, $Q(x_2, t_n) = \sum_{i=0}^{n} q(x_2,t_i)$

At the beginning of the experiment

$Q(x_1, t_0) = 0$ and $Q(x_2,t_0) = -n(t_0) \leq 0$

The number of vehicles traveling on the link at time t_n is then given by

$$n(t_n) = Q(x_1,t_n) - Q(x_2, t_n)$$

The density at time t_n is thus given by $k(t_n) = (Q(x_1,t_n) - Q(x_2, t_n))/ \Delta x$

The number of vehicles entering as well as exiting during the interval (t_{n-1},t_n) defined as

$$m(t_n) = Q(x_2,t_n) - Q(x_1, t_{n-1}) \tag{2.2.1.2}$$

Under normal traffic conditions, $m(t_n)$ is always positive. It can be either zero or negative if traffic is jammed so that no vehicles that entered the link previously have exited during the interval (t_{n-1}, t_n), i.e. traffic is conceptually under congested conditions. The travel time functions are derived for cases where $m(t_n)$ is positive and otherwise. When $m(t_n)>0$, the average travel time during the interval (t_{n-1}, t_n) is derived to be

$$tt(t_n) = \frac{[q(x_1,t_n) + q(x_2,t_n)]k(t_{n-1})\Delta x + [q(x_1,t_n) - q(x_2,t_n)]q(x_2,t_n)\Delta t}{2q(x_1,t_n)q(x_2,t_n)} \tag{2.2.1.3}$$

When $m(t_n) <0$, the travel time during interval (t_{n-1},t_n) is derived to be

$$tt(t_n) = \frac{k(t_{n-1})\,\Delta x + [q(x_1,t_n) - q(x_2,t_n)]\Delta t}{2q(x_2,t_n)} \tag{2.2.1.4}$$

The two expressions shown above for travel time estimation are used when there is normal traffic flow on the freeway or when there is a small degree of congestion. When there are incidents or lane closures on freeways, these relationships do not hold and they cannot be used to calculate travel times. It should be noted that in order to implement this method in real time, information about the number of vehicles on a link at the start of calculations is necessary. Moreover, the travel time estimates are very sensitive to errors measurement at the detector stations.

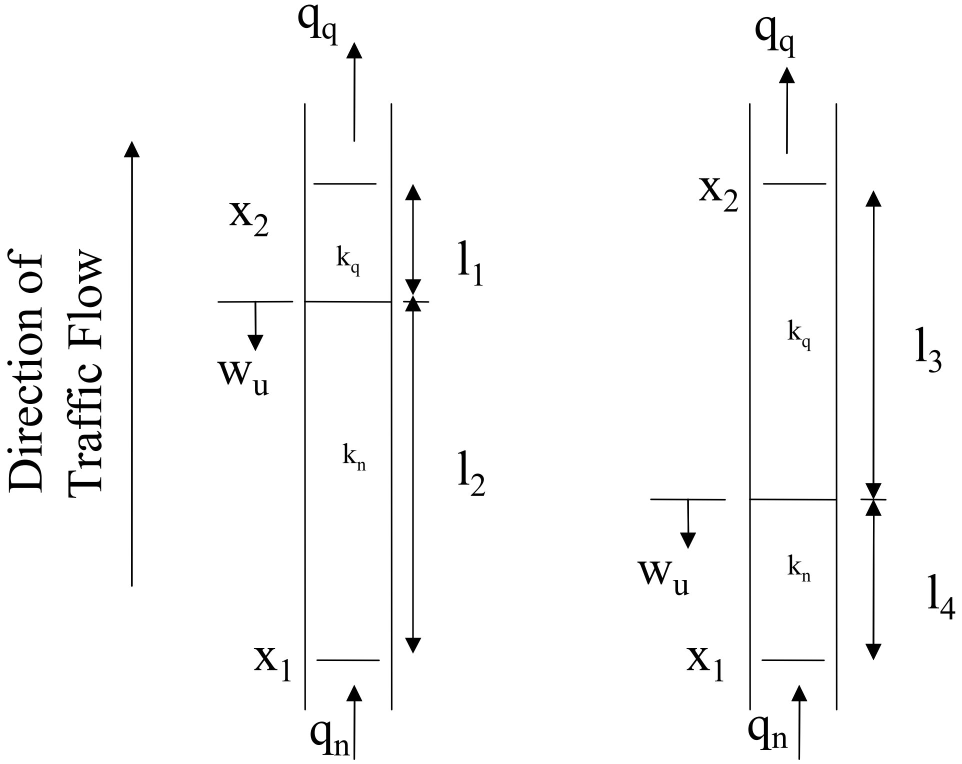
When there are incidents or lane closures on freeways, the authors provided methods for estimating delays in order to assist in diversion plans. This case is subdivided into two categories.

(2.2.1.1) When there is temporal surge in demand

(2.2.1.2) When there is an incident leading to transient reduction in capacity

Consider a link on a freeway as shown in Figure 2.2.1.2. The link has a bottleneck at the downstream end near x_2. The link is under recurring congestion in which the demand of traffic exceeds the capacity of the bottleneck. Two different traffic flows will be observed –approaching flow that represents demand (Flow = q_n Density =k_n), and queuing flow that represents traffic under congestion at the bottleneck (Flow =q_q Density = k_q).

On the freeway segment between x_1 and x_2, the longitudinal length of queuing flow and approaching flow are l_1 and l_2 at time t and l_3 and l_4 at time ($t + \Delta t$).



Time t **Time t + Δt**

Figure 2.2.1.2: Increase in congestion domain during time Δt

(Source: Nam and Drew, 1995)

Now the principle of conservation of vehicles is applied for deriving the queuing rate The difference between the number of vehicles that entered the segment during the period Δt and that exited the segment during the same interval is

$$(q_n - q_q)\,\Delta t \qquad (2.2.1.5)$$

The change in number of vehicles traveling on the segment during the same period is given as $(k_q\, l_3 + k_n\, l_4) - (k_q\, l_1 + k_n\, l_2)$. Using the relationship $l_1 + l_2 = l_3 + l_4$ this can be written as

$$(k_q - k_n)(l_3 - l_1) \qquad (2.2.1.6)$$

By principle of conservation of vehicles, (2.2.1.5) and (2.2.1.6) are identical

Hence, $(q_1 - q_q)\,\Delta t = (k_q - k_1)(l_3 - l_1)$ or,

$$\frac{(l_1 - l_3)}{\Delta t} = \frac{q_q - q_n}{k_q - k_n} = w_u \qquad (2.2.1.7)$$

Here, $(l_1\text{-}l_3)$ / Δ t is the speed of movement of the frontal boundary between the two flows and, by definition, is the velocity of a shockwave w_u.

Let n be the number of vehicles in a queue. The queuing rate during the period Δt is equal to the additional vehicles that are included in a queue during this period, and is obtained as

$$\frac{\Delta n}{\Delta t} = \frac{k_q(l_3 - l_1)}{\Delta t} \qquad (2.2.1.8)$$

This can be written as

$$\frac{\Delta n}{\Delta t} = (q_n\text{-}q_q) + w_u k_n \qquad (2.2.1.9)$$

This is the queuing rate of vehicles.

w_u is negative in case of backward forming shockwave and positive in case of forward recovery shockwave. A forward recovery shockwave is denoted by w_d.

The rate of progression in case of backward forming shockwave is

$$\frac{dn}{dt} = (q_n - q_q) - w_u k_n \qquad (2.2.1.10)$$

The rate of retrogression in case of forward recovery shockwave is

$$\frac{dn}{dt} = (q_c - q_q) + w_d k_n \qquad (2.2.1.11)$$

The theory of shockwaves is now applied to estimation of delays in case of temporal surge in demand and in case of transient reduction in capacity.

(2.2.1.1) **When there is temporal surge in demand**: Temporal surge in demand occurs when the demand exceeds capacity of a facility. For example, in case of work zones leading to closure of lanes, the upstream flow exceeding the capacity of the lane closure during the morning peak can be considered a temporal surge in demand.

In this case (Figure 2.2.1.3) the total delay is estimated as

$$TD = (T_2Q_1 - T_1Q_2)/2 \qquad (2.2.1.12)$$

where, T_1 is time at which the increasing demand stops to grow and drops below capacity and T_2 is time at which queue of delayed vehicles disappears, while Q represents cumulative flow. The measurement of T_1 and T_2 start from time 0.

$$Q_1 = (q_d\text{-}q_c)T_1+(-w_u k_u)T_1 \qquad (2.2.1.13)$$

q_d is the demand flow q_c is the capacity flow

$$Q_2 = q_c T_2 \qquad (2.2.1.14)$$

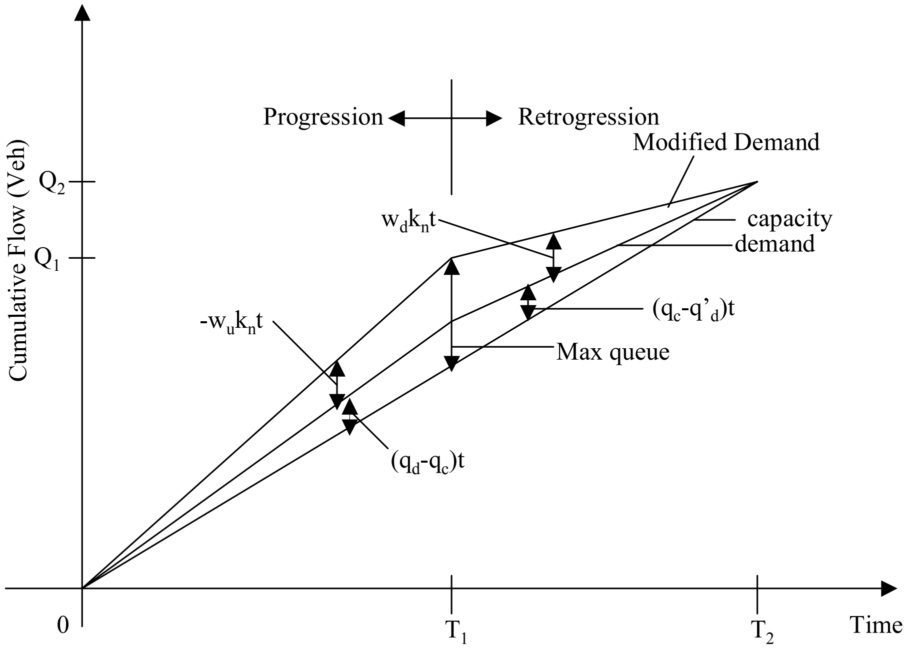


Figure 2.2.1.3: Delay diagram in case of temporal surge in demand

(Source: Nam and Drew, 1995)

(2.2.1.2) **When there is an incident leading to transient reduction in capacity**: In this case, (Figure 2.2.1.4) at time T_1 the incident is cleared completely and capacity of the road recovers to its full capacity. At this instant, a backward recovery shockwave w'_u develops and travels against the direction of traffic. It intersects w_u at time T_2 and prevents the incident domain from progressing further. The queue reaches its maximum length at that time. After time T_2, the domain of the incident retrogresses at a rate of forward recovery shockwave w_d and the queue finally disappears at time T_3. The speeds of two backward shockwaves are

$$w_u = \frac{q_d - q'_c}{k_d - k_j} < 0 \qquad (2.2.1.15)$$

where q'_c, k_j are for reduced capacity flow and q_d, k_d are for demand flow.

$$w'_u = \frac{q_c - q'_c}{k_c - k_j} < 0 \quad (2.2.1.16)$$

where q_c and k_c are for capacity flow.

The speed of the forward recovery shockwave is

$$w_d = \frac{q_c - q_d}{k_c - k_d} > 0 \quad (2.2.1.17)$$

The maximum queue length l_{max}, which is formed at time T_2, is derived as

$$l_{max} = \frac{w_u w'_u T_1}{(w_u - w'_u)} \quad (2.2.1.18)$$

The time T_2 can be calculated as

$$T_2 = \frac{w'_u T_1}{w'_u - w_u} \quad (2.2.1.19)$$

The time T_3, the time at which the queue finally disappears, can be calculated as

$$T_3 = \frac{w'_u (w_u - w_d)}{w_d (w_u - w'_u)} T_1 \quad (2.2.1.20)$$

The total delay in this case TD is estimated as

$$TD = (T_1 Q_3 + T_3 Q_2 - T_3 Q_1 - T_2 Q_3)/2 \quad (2.2.1.21)$$

where,

$Q_1 = q'_c T_1$;

$Q_2 = l_{max} k_c + (T_2 - T_1) q_c + Q_1$;

$Q_3 = (T_3 - T_1) q_c + Q_1$

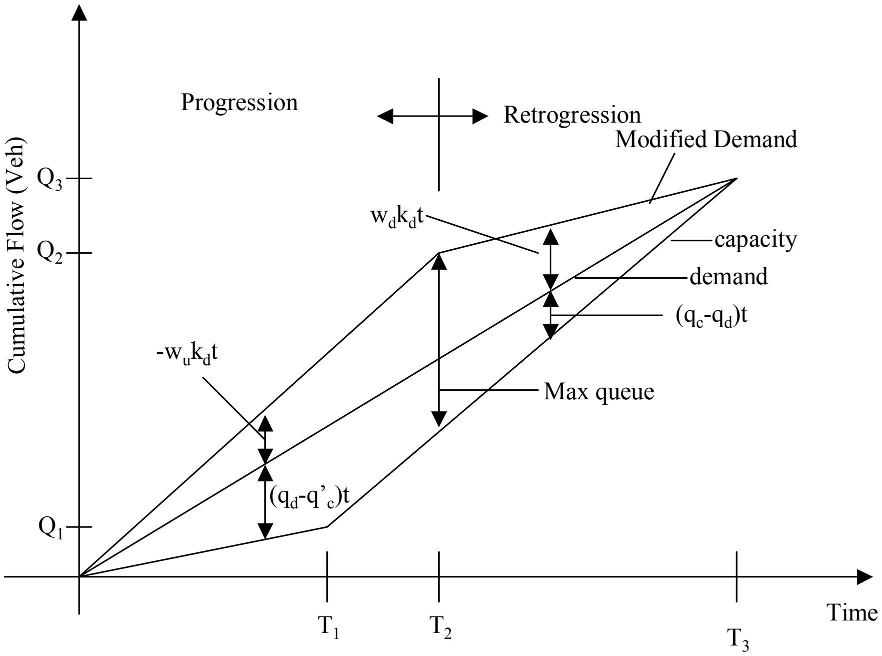


Figure 2.2.1.4: Delay diagram in case of temporal reduction in capacity

(Source: Nam and Drew, 1995)

The delay calculations shown in the above cases are useful for making diversion decisions. The methods, however, do not have direct application in travel time estimation at regular intervals from detector output under incident conditions and under temporal surge in demand. The methods focus on general discussion of methods to calculate overall delays, rather than individual estimates of travel times. The method provided is not applicable in real-time based on point estimates of traffic parameters. The current research tries to provide a solution to this problem by formulating a method for travel time estimation under incident conditions and under temporal surge in demand based on point estimates at a macroscopic level.

2.2.2 INPUT – OUTPUT DIAGRAM METHOD

Lawson, Lovell and Daganzo (1998) presented a simple and lucid method for estimating spatial and temporal extents of a queue upstream of a bottleneck using Input-Output diagram. This method finds direct application in travel time estimation. They mention that though time-space diagram can be used to solve the problem directly and correctly, it is a tedious process. Their proposed method estimates time and distance spent by vehicles in a queue in a much simpler manner than a time-space diagram. It requires the construction of cumulative vehicle curves (Figure 2.2.2.1). The authors also clarify the difference between distinct concepts of 'delay' and 'time in queue', which were objects of confusion in some literature. Delay represents the difference between time a vehicle actually took to traverse a given distance and time it would have taken if it were unobstructed. Time in queue on the other hand is the amount of time a vehicle actually spends in queue.

A bottleneck with constant maximum departure rate μ is considered and analyzed under both conventional time-space and proposed input-output diagram methods. In both cases, a constant free flow speed v_f is assumed to hold for all uncongested traffic (independent of flow). A constant speed v_μ, which depends upon the bottleneck flow, is assumed in the queue whenever there is congestion and queue formation upstream of a bottleneck. Some other assumptions were made to avoid complexity. The equations relating delay w, the time spent in queue t_Q(>w) and the distance traveled in queue d_Q for an individual vehicle are derived from the time-space diagram.

$$w = \left(\frac{1}{v_\mu} - \frac{1}{v_f}\right) d_Q \qquad (2.2.2.1)$$

$$t_Q = \frac{d_Q}{v_f} = \frac{w}{1 - \frac{v_\mu}{v_f}} \qquad (2.2.2.2)$$

Now, the input-output diagram is constructed. The arrival time of each vehicle at an upstream observation point is measured and plotted on the figure as curve A(t). Then, the desired (or "virtual") arrival time of each vehicle at the bottleneck is plotted as curve V(t) by translating the arrival time of each vehicle horizontally to the right by the free-flow travel time to the bottleneck t_f. This curve would represent the actual time of arrival of each vehicle at the bottleneck if there were no queuing. But, since the vehicles face congestion and delays due to queuing upstream of the bottleneck, they depart along the departure curve D(t), which is constructed based on the maximum rate of departure μ. The curve representing the cumulative number of vehicles to reach the back of the queue, B(t), can be drawn by extending the delay of each vehicle w_n, to the left as shown in Figure 2.2.2.1.

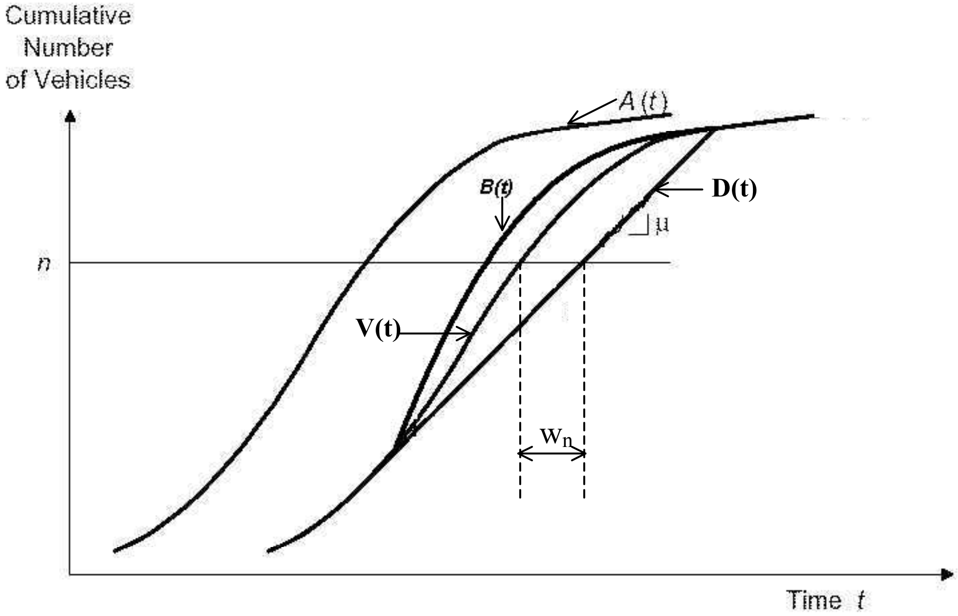


Figure 2.2.2.1: Input output diagram

(Source: Lawson, Lovell and Daganzo (1998))

The number of vehicles in queue at time t can be conveniently determined by the vertical separation between B(t) and D(t) curves. The vertical separation between V(t) and D(t) represents the number of vehicles in the imaginary point queue. The maximum length of queue Q_{max} and maximum time a vehicle spends in queue t_{max} are related as

$$Q_{max} = \mu \, t_{max} \qquad (2.2.2.3)$$

The maximum queue length expressed in physical distance is

$$D_{max} = Q_{max} \frac{v_\mu}{\mu} = t_{max}\ v_\mu \qquad (2.2.2.4)$$

This method can be easily automated in a spreadsheet. The information that needs to be known to do so is

A_n -> The arrival time of each vehicle n at the upstream observer

μ -> Bottleneck Capacity

v_f and v_μ -> The free flow and congested speeds

t_f -> The free flow travel time from observation point to the bottleneck

For each vehicle n, the desired or virtual arrival time at the bottleneck can be calculated as

$$V_n = A_n + t_f \qquad (2.2.2.5)$$

The departure time of first vehicle is assumed to be $D_1 = V_1$ i.e it passes without delay. For the remaining vehicles, the departure time can be calculated as

$$D_n = \max(V_n, D_{n-1} + 1/\mu) \qquad (2.2.2.6)$$

and delay of an individual vehicle is

$$w_n = D_n - V_n \qquad (2.2.2.7)$$

The travel time for any vehicle can be calculated as $tt_n = t_f + w_n$

The total travel time of vehicles and total distance traveled by them can be calculated by adding up the individual travel times and distances. The number of vehicles in queue at time t is the physical queue length at that time, d_Q multiplied by the density of vehicles in queue($k_\mu = \mu/v_\mu$)

$$\text{No. of vehicles in queue} = d_Q\ k_\mu \qquad (2.2.2.8)$$

The authors do not address the issue of how aggregated point estimates can be used to determine travel times. Obtaining and storing the arrival time data for individual vehicles is not easy to implement in real time. For real time ATIS applications, a macroscopic model that is less data hungry is required. The methods discussed thus far indicate that it is important to know the time of clearance of an incident to accurately estimate the delays that will be caused.

2.3 INCIDENTS ON FREEWAYS AND TRAVEL TIME

In order to apply the methods for travel time estimation correctly when incidents occur on freeways information such as number of lanes blocked by the incident, the reduction in capacity caused and the duration of the incident need to be determined. Information about the number of lanes closed is directly obtained from the scene of the incident. The reduction in capacity due to the incident and the duration of the incident can be estimated based on the characteristics of the incident.

Literature is reviewed for information about the capacity and duration of incidents. It will be worthwhile to first look at the definition of an incident. An incident is defined as any occurrence that affects roadway capacity, either by obstructing travel lanes or by causing gawkers block. (Giuliano, 1989) Accidents are one type of incidents on freeways. There can be other types of incidents like flat tires, police stopping vehicles for ticketing, breakdowns, abandoned vehicles, spills etc. Sullivan (1997) classified incidents into seven standard types as follows:

1. Abandoned Vehicles
2. Accidents and fires
3. Debris on the highway
4. Mechanical, electrical, fuel, and cooling system failures which generally lead to towing away of vehicles.
5. Stalled vehicles, which typically need brief roadside attention only.
6. Tire problems
7. Other, which include miscellaneous events such as pedestrians walking along freeways, roadside fires, etc.

Incidents have known to be the cause for major congestion problems on urban freeways. Traffic incidents cause reduction in traffic flow either directly by lane closure or indirectly by gawkers slowing down to look at the incident. Many studies have been conducted in the past to quantify the magnitude of the problem of congestion due to incidents on freeways. It was found that congestion due to incidents constitutes somewhere between one-half and three-fourths of the total congestion on urban freeways (Kolenko and Albergo, 1962; Lindley, 1987).

Earlier studies indicate that the impact of incidents on facility capacity is quite consistent. The effect depends on facility characteristics as well as characteristics and location of the incident itself. Incidents affect capacity even when no lane blockage occurs. Estimates on the impact of gawkers block are on the order of 25%. (Lari et al, 1982; Goolsby et al, 1971)

The incidents that have most adverse affect on travel times are the ones in which there is a lane blockage. Even in freeways where there are shoulders, it was found that about 20% of the incidents lead to lane blockage (Giuliano, 1989). In case there is no shoulder available, the percentage will be much higher. Lane blocking incidents reduce the capacity sometimes proportionately and sometimes more than proportionately. For example, when a lane is blocked causing 33% reduction in spatial extent, freeway capacity reduction varies from 33% to 55 % (Urbanek et al, 1978). As the capacity is reduced, queue builds up on the freeway. The extent of the queue depends on the level of demand during the incident, the duration of the incident and the degree of capacity reduction. (Giuliano, 1989) The larger the queue, the longer it takes for normal operations to be restored on the freeway.

Duration of an incident depends on many factors. The time the incident takes place, the extent of lane closure, incident type, response time, clearance time and queue dissipation rate are some of the major factors that determine the delays caused to the vehicles as shown in Figure 2.3.1. In order to analyze the impacts of incidents, information on all these factors is required. When an incident occurs on a freeway, before traffic is restored again to normal state, the following phases transpire.

2.3.1 Incident detection and verification: The incident can be detected from point data using standard algorithms like the California algorithm. Once the incident is detected and confirmed by the algorithms in the traffic control center, an incident flag is raised and concerned authorities are immediately notified for response. Incident truth is then verified from the information obtained from road users. Emergency personnel are deployed to provide assistance to those involved in the incident. Incident detection based on detector data has been a major research area for many years. Many algorithms, both analytic and Artificial Intelligence based were developed and tested to get quick and accurate detection of incidents on freeways (Jin et al, 2002; Payne et al, 1978). The information given by road users can be used to verify the incident detection algorithms at the traffic control center. The capacity of the freeway drops when the incident occurs as shown in the figure. If the demand is greater than the capacity, then, the vehicles arriving at the incident location will face delays and the delays of vehicles arriving will continue to increase as long as the capacity is less than the demand.

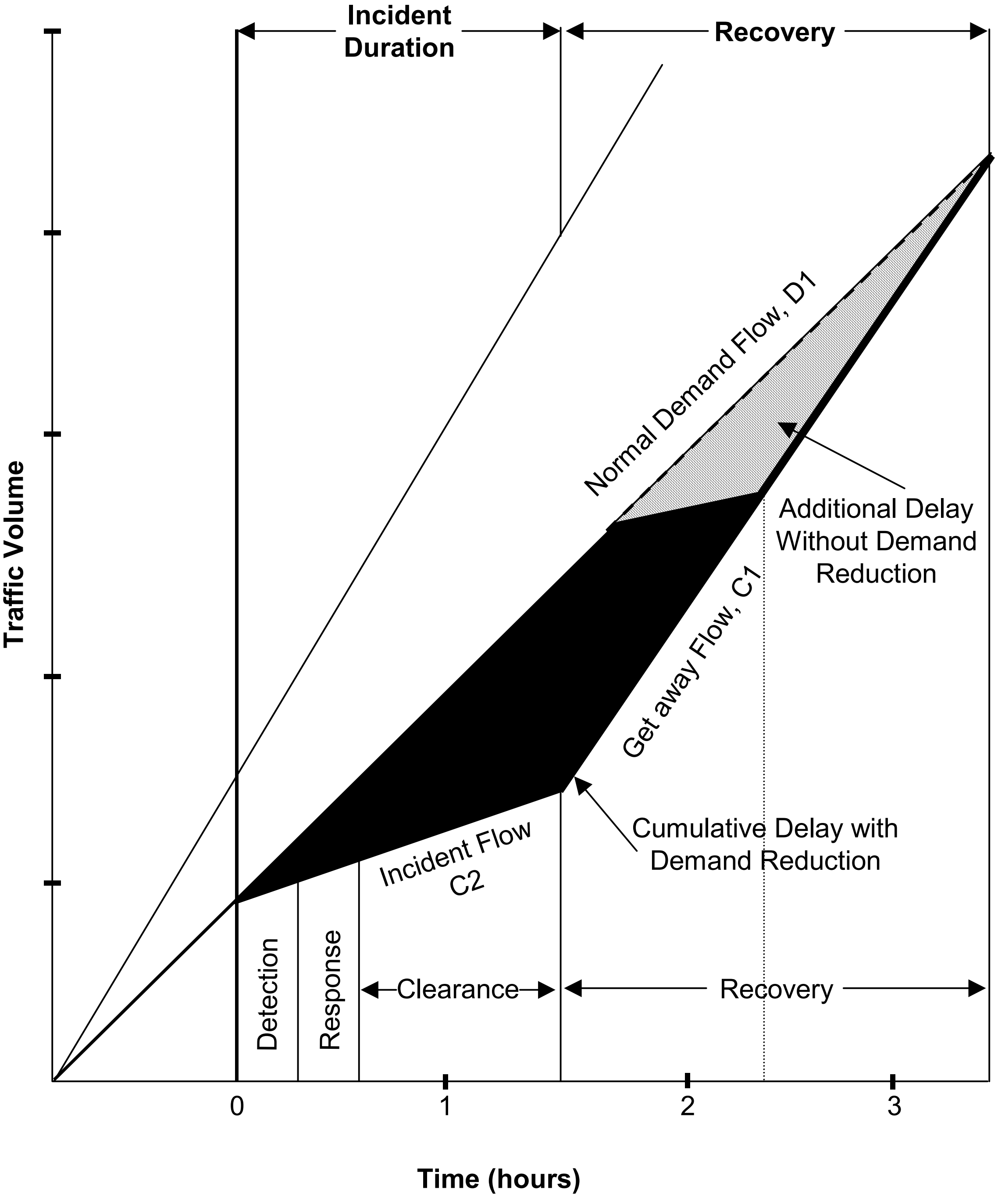


Figure2.3.1: Delays Caused by Incident on Freeway

(Adapted from Lindley, 1987)

2.3.2 Response: Once the occurrence of the incident has been confirmed, ambulances, police, tow trucks and any other required response units rush to the scene. This phase is known as the response phase. The total time taken, from the time of occurrence of the incident to the time when the emergency response units reach the scene, is known as the response time. Literature indicates that response time on freeways varies from 10 to 25 minutes and it depends on many factors (Sullivan, 1997). In this phase too, the reduced capacity of the freeway continues to affect the delays caused to the vehicles arriving at the scene of the incident.

2.3.3 Clearance: After the emergency personnel reach the scene of the incident, they work on clearing the incident from the freeway and providing assistance to those involved in the incident. Prediction of incident clearance time was discussed by Wang et al (1991) and by ADVANCE project group (Sethi et al 1994). However, these models used a small data set as their basis. Kaan and Hobeika (1997) analyzed the data collected by Subramaniam et al (1993) to study effect of the various characteristics of incidents on clearance times. Clearance time for incidents was modeled based on the following factors: lane closure, number of cars involved, number of trucks involved, number of personal injuries, number of fatalities, hazmat involvement, fire involvement, time frame of occurrence, prevailing weather, prevailing temperature, land use type. A classification and regression tree analysis was conducted to study the effect of the various hypothesized variables on the clearance of incidents. It was found that most of the factors have good influence on the clearance times. Based on these results prediction/decision trees were constructed. The main features of this study were as follows:

a) If there is no information available about the incident type, then the mean clearance time is 25 minutes.
b) If the type of the incident is known it is classified into one of the eight major types of incidents. Incidents are classified into the following types: road hazard, property damage, personal injury, disabled truck, vehicle fire, HAZMAT (Hazardous Material), and disabled car or truck in lane. Then, each of these incident types is analyzed by further classification based on information about the number of ambulances and wreckers used, the number of police vehicles on the scene and whether the disablement is on the shoulder or not.

c) The prediction/decision trees were validated with a new data set and the results were found to be satisfactory for incident management purposes.

A refined form of the trees is developed as part of the current research. The capacity of the freeway increases after the clearance and this will lead to reduction in the delays caused to the vehicles arriving at the queues.

2.3.4 Recovery: Once the incident is declared as cleared, the queue that built up will start dissipating at a faster rate than before and traffic flow will reach normal conditions eventually. The time taken for traffic to reach normal conditions once the incident is cleared is known as recovery time. Recovery time is directly dependent on rate of discharge after the incident. Various researchers have studied the rate at which vehicles are discharged from a bottleneck and after clearance of incidents. Cassidy and Bertini (1998) found the average rate at which vehicles are discharged can be 10% lower than the rate measured prior to the queue's formation based on study of queues at bottlenecks near Toronto, Canada. Ringert and Urbanik (1993) studied freeway bottlenecks in Texas and found that while average free- flow rates ranged from 2096 to 2210 vehicles per hour per lane (vphpl) across all lanes, the queue discharge flow rates averaged approximately 2175 vphpl for the study sites.

One of the main objectives of the current research is developing a system for estimating travel times which works reliably during incidents and lane closures and thus, the results of earlier research on characteristics of incidents and traffic discharge rates near bottlenecks are utilized in developing the system.

CHAPTER 3 THE SYSTEM FOR TRAVEL TIME ESTIMATION

3.1 INTRODUCTION

The objective of this chapter is to present the system developed for estimation of travel times from detector data. The system comprises of three cases (Case A, Case B and Case C). The first case (Case A) deals with travel time estimations under lane closures, which can be used for travel time estimation when there is a lane closure on freeways for maintenance or for any other reason. This Case A algorithm is also referred to as "Bottleneck algorithm". The second case (Case B) deals with travel time estimation under incident conditions. This algorithm is applicable when an incident occurs on a freeway, thus leading to closure of one or more lanes. In this case, it is important to estimate when the incident is cleared to calculate travel times accurately. This Case B algorithm is also referred to as the "Incident Algorithm". The third case (Case C) deals with travel time estimation when there is no incident or lane closure on the freeway. In this case travel time is estimated based on density of traffic on the freeway. The Case C algorithm is also referred to as " No-incident No-Closure case Algorithm".

Figure 3.1.1 shows the framework for travel time estimation on urban freeways. The input to the system is aggregated detector data obtained from various detector locations on a freeway. It can be either direct measurements like vehicle counts and occupancy or processed measurements like flow and density at periodic intervals. The calculations are started with link i for time period 'n'. They are next performed for other links till travel times are evaluated for all links for the first time period. The calculated travel times are stored in archives for system evaluation and prediction purposes. The travel times are also broadcast to road users through various media. Then, calculations are performed for the next time period again for all the links and the process is repeated as long as travel time estimates are needed.

For calculating travel times on the link i in consideration for the time period n, it is first checked whether there is an incident on the link. In case there is an incident, Case B algorithm is used for travel time estimations. In case there is no incident on the freeway it is checked whether there is a lane closure on the link. If one or more lanes are closed on the link for maintenance or any other reasons, it is checked if upstream flow arriving on the link is greater than the downstream capacity. In case the upstream flow is greater, the Case A algorithm is used to calculate travel times. In case the upstream flow is not greater than the capacity, there will be no queuing at the bottleneck and hence travel time estimation is done using Case C algorithm. Also, in case there is no lane closure or incident on the freeway, travel times are estimated using Case C algorithm. A detailed description of the procedures for calculating travel times is presented in sections 3.2, 3.3 and 3.4 which deal with Case A, Case B and Case C algorithms respectively.

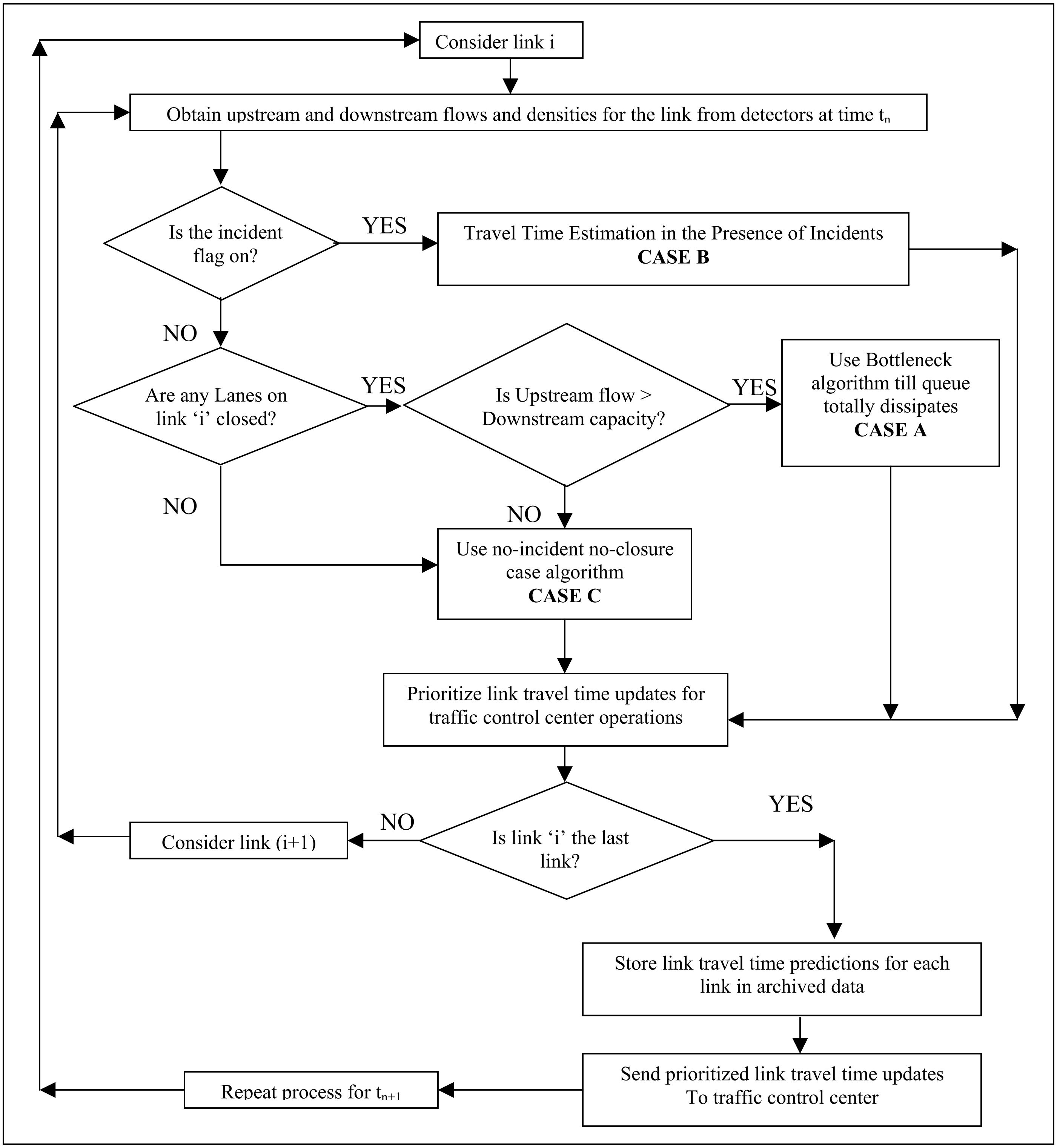


Figure 3.1.1: Framework for Travel Time Estimation on Urban Freeways

3.2 CASE A: TRAVEL TIME ESTIMATION UNDER LANE CLOSURE

The procedure for estimating travel times when there is a lane closure is Case A and is described next. This algorithm is applicable when the number of lanes on a link is reduced due to any reason, like maintenance, repair or due to space limitations as shown in Figure 3.2.1. The capacity of the lane drop location is assumed to be constant over time. As discussed in Chapter 2, the capacity of bottlenecks has been a topic of research for quite some time and results vary from location to location. The capacities have been found to vary from 1800 to 2200 vehicles per hour per lane (vphpl). When the demand on the link exceeds this capacity, a backward forming shockwave will form on the freeway. This shockwave originates just behind the bottleneck and travels backward against the direction of the traffic. The shockwave affects the traffic upstream of the closed lane and a queue builds up on the freeway. The shockwave can be visually observed as the boundary between the queuing traffic and the traffic arriving upstream. The higher the difference between upstream arriving flow and downstream capacity, the greater will be the shockwave speed.

A description of variables used in the algorithm is provided first. The detectors are named DT in the Figure 3.2.1 and there are five of them. These are the detector on link (i-1), detector on link (i+1) and three detectors on link i. The link i is assumed to have three detectors, one at the upstream section, one at the start of the bottleneck and one at the end of the link. The flows are designated in Figure 3.2.1 by ‘q’ and the densities by ‘k’. The capacity of the bottleneck is assumed to be C vphpl. The three links in consideration are link (i-1), link i and link (i+1). The link for which travel time is being calculated is the link i. The link upstream of link i is link (i-1) and, the link downstream of link i is link (i+1). ‘N’ designates the number of lanes. The subscripts to the symbols refer to the link that they represent and, the location of the detector on the link. For example, N_{i_u} represents the number of lanes on link ‘i’ at the upstream end.

From Figure3.2.1, it is assumed that upstream detector DT_{i_u} is available and functioning for the link i. The capacity of the bottleneck is calculated from the detector DT_{i_b}. In case the detector is unavailable or not functioning, the capacity is assumed to be some constant value C between 1800-2200 vphpl, that the user can specify.

Then, if at time $t_{0,}$

$$\overline{q}_{i_u} \times N_{i_u} \le C \times N_{i_b}$$

i.e., upstream flow arriving on the link i is less than the bottleneck capacity, then, no congestion is imminent. Normal travel time estimations as for no closure and no incident case are used.

If at time t_0

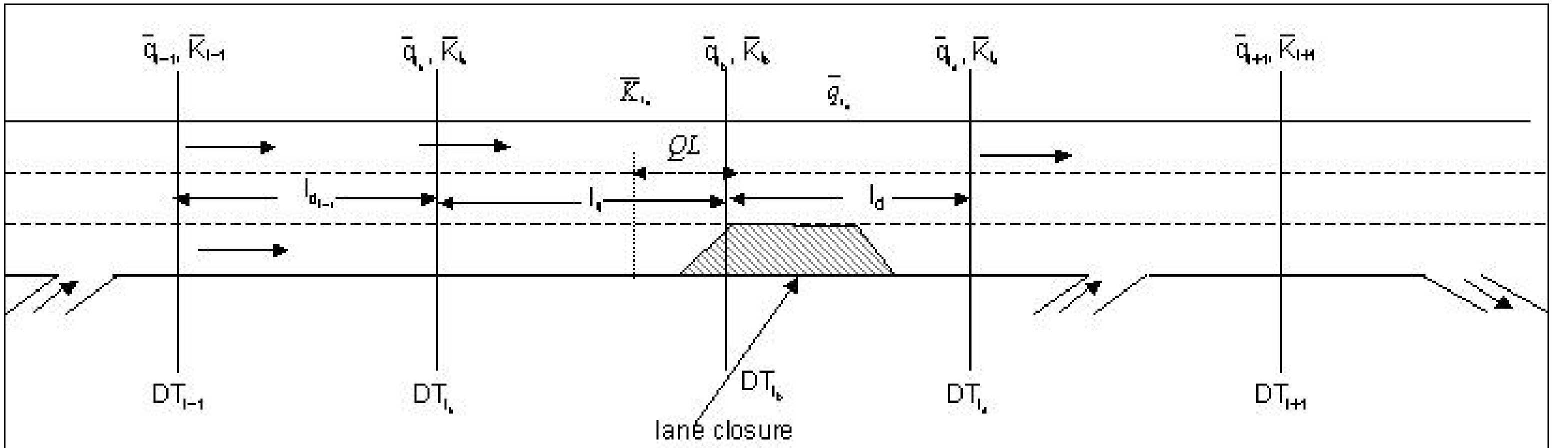
$$\overline{q}_{i_u} \times N_{i_u} > C \times N_{i_b}$$

then, congestion is imminent as the number of vehicles approaching is higher than number of vehicles departing. Vehicles will start to queue behind the bottleneck. Density at the bottleneck can be assumed to be $\overline{K}_{i_b} = 110 - 130$ vpmpl in the queue.

In case Detector DT_{i_u} is malfunctioning, the historical flows and densities $\overline{q}_{i_h}$ and $\overline{K}_{i_h}$ from archived data are used for the link i for the same day type and the same time period.

Now that the required flows and densities are determined they are used in the algorithm. The algorithm is divided into two components, the queue building case and the queue dissipation case. It should be noted that as long as the upstream flow is greater than the capacity of the bottleneck, the queue continues to grow. The 'Queue Building Case' is used under these conditions. Once the arrival rate of traffic upstream of the bottleneck falls below the capacity of the bottleneck, the queue will start to dissipate. The 'Queue Dissipation Case' is used under these conditions.

The following are the various steps in the algorithm.



DT = indicates the detector location on the freeway

$\bar{q}$ = is the average flow (vehicle per hour per lane, vphpl) at that detector location

$\bar{K}$ = is the average density (vehicle per mile per lane, vpmpl) at that location . It is calculated as: density (k) = 2.3 Occupancy (OCC). In the QL area It is 120 vpmpl.

N_b = number of available traffic lanes at the bottleneck on link (i).

N_a = number of available traffic lanes downstream of the bottleneck on link (i)

N_u = number of available traffic lanes upstream of the bottleneck on link (i)

$N_{(i+1)}$ = number of available traffic lanes downstream of link (i) on link (i+1)

$N_{(i-1)}$ = number of available traffic lanes upstream of link (i) on link (i-1)

l_d = the distance in miles from the start of the bottleneck to the downstream node (end node of link (i))

l_u = the distance in miles from the start of the bottleneck to the upstream node (end node of link (i))

$l_{d_{i-1}}$ = the distance in miles from the detector DT_{i-1} to the downstream node (end node of link i-1)

l_{i-1} = the length in miles of link (i-1)

Figure3.2.1: Bottleneck

QUEUE BUILDING CASE

Step 1

The velocity of the backward forming shock-wave upstream of bottleneck is determined in (mph). It moves against the direction of traffic as long as the queue is building. Hence, its velocity is always negative in the queue building case:

$$W_u = \frac{(\overline{q}_{i_u} \times N_{i_u} - C \times N_{i_b})/N_{i_u}}{\overline{K}_{i_u} - \overline{K}_{i_b}} \qquad (3.2.1)$$

W_u is negative since the denominator is negative indicating the backward movement of the shock wave

The Queuing Rate (QR) (veh/hr) is:

$$QR = \frac{dn}{dt} = \left(\overline{q}_{i_u} \times N_{i_u} - C \times N_{i_b} - W_u \times \overline{K}_{i_u} \times N_{i_u}\right) \qquad (3.2.2)$$

Step 2

The number of vehicles in queue (Q) at time $(t_0 + n\,\Delta t)$ is determined, where Δt is the time interval for travel time update on this link (i). Δt is considered to be 5 minutes generally, and n is the number of update cycle from time t_o.

$$Q_n = QR \times \Delta t_n \qquad \text{where } n = 1, 2, 3 \ldots m \qquad (3.2.3)$$

'm' is reached when $\overline{q}_{i_u} \times N_{i_u} \leq C \times N_{i_b}$ i.e. when the approaching flow rate is less than the capacity of the bottleneck. The process is repeated for every interval and the total number of vehicles in queue is estimated using the following expression.

$$Q_m = \sum_{n=1}^{m} Q_n \qquad (3.2.4)$$

Step 3

The travel time $\left(\overline{tt}_{b_n}\right)$ in hours for a vehicle just entering the queue is determined next. This is estimated based on the assumption that for Q_m vehicles to leave the queue at a rate of C vehicles per hour per lane from N_{i_b} lanes, the average time required would be

$$\overline{tt}_{b_n} = \frac{Q_m}{C \times N_{i_b}} \qquad \text{hours, for } n = 1, 2, 3 \ldots m \qquad (3.2.5)$$

This time is the same as the time required for the last vehicle to leave the queue. It is important to note that this equation is based on the assumption that the downstream flow remains constant. The situation is analogous to a sandglass being emptied.

Step 4

The Queue Length (QL) in miles from the start of the bottleneck is determined:

$$QL = \frac{Q_m}{\overline{K}_{i_b} \times N_{i_u}} \tag{3.2.6}$$

The above equation is valid as long as QL $\leq l_u$ (where l_u is the distance from the lane drop location to the upstream detector. If QL $\geq l_u$, then data from the upstream detector is not valid any longer as the queue has crossed the detector and spilled over into the immediately upstream link (i-1). $\overline{q}_{i_u}, \overline{k}_{i_u}$ are replaced with $\overline{q}_{i-1}, \overline{k}_{i-1}$ in the next update cycle where, $\overline{q}_{i-1}$ is the flow on the immediately upstream link (i-1) and $\overline{k}_{i-1}$ is the density given by detector on link (i-1). More specifically,

if $$l_u \leq QL \leq l_u + l_{d_{i-1}}, \tag{3.2.7}$$

then the back of queue has not crossed the detector on the immediately upstream link (i-1). $\overline{q}_{i-1}$ and $\overline{K}_{i-1}$ are used as the flow and density of the approaching traffic on link (i) in the next update cycle.

if $$QL > l_u + l_{d_{i-1}}, \tag{3.2.8}$$

then, the queue has crossed the detector on link (i-1). $\overline{q}_{i-2}$ and $\overline{K}_{i-2}$ values are used as the approaching flow and density values for the next update cycle.

Steps (3.2.6) and (3.2.7) are repeated for links l_{i-3}, l_{i-4} and so on if necessary.

Step 5

The travel time (TT_i) in hours on the link (i) can be determined now. If QL $\leq l_u$ then the travel time on the link i is split into three components. First component is the travel time upstream of the queue, second component is the travel time in queue and third component is the travel time downstream of the queue. The travel time upstream of the queue is estimated by dividing the length of the un-congested section by the average speed in the un-congested section. The average speed in the un-congested region is found by dividing the flow by the density (obtained from the upstream detector). The travel time in the congested region is found as described in equation (3.2.5). The travel time downstream of the congested region is again determined by dividing the length by the average speed.

$$TT_i = \left(l_u - QL\right) \Big/ \frac{\overline{q}_{i_u}}{\overline{K}_{i_u}} + \overline{tt}_{b_n} + l_d \Big/ \frac{\overline{q}_{i_d}}{\overline{K}_{i_d}} \tag{3.2.9}$$

If QL > l_u, i.e if the queue has crossed the link i and spilled into link (i-1), then travel time on link (i) has only two components. The travel time in queue and the travel time downstream of the queue:

$$TT_i = \overline{tt}_{b_n} \times \frac{l_u}{QL} + l_d \Big/ \frac{\overline{q}_{i_d}}{\overline{K}_{i_d}} \tag{3.2.10}$$

In this case the travel time on link l_{i-1} can be calculated as follows:

If $QL - l_u \le l_{d_{i-1}}$ i.e if queue has not spilled link (i-2)

$$TT_{i-1} = \overline{tt}_{b_n} \times \frac{QL - l_u}{QL} + \left[l_{i-1} - \left(QL - l_u\right)\right] \Big/ \frac{\overline{q}_{i-1}}{\overline{K}_{i-1}} \tag{3.2.11}$$

If QL – l_u > $l_{d_{i-1}}$, i.e. if queue has spilled into link (i-2)

$$TT_{i-1} = \overline{tt}_{b_n} \times \frac{l_{i-1}}{QL} \tag{3.2.12}$$

Step 6

Steps 1 to 5 are repeated for the next update cycle of Δt and so on until the cycle (m) is reached where; $\overline{q}_{i_u} \times N_{i_u} \le C \times N_{i_b}$. Then the following steps are executed.

QUEUE DISSIPATION CASE

Step 1'

When arriving flow is less than the bottleneck capacity, the backward forming shockwave stops progressing further and a forward recovery shockwave is formed. The shockwave has a positive velocity and moves in direction of the traffic as the queue length decreases gradually.

The forward moving shock wave velocity (W_d) is calculated as follows:

$$W_d = \frac{\left(C \times N_{i_b} - \bar{q}_{i_u} \times N_{i_u}\right)/N_{i_u}}{\bar{K}_{i_b} - \bar{K}_{i_u}} \qquad \text{(always positive)} \qquad (3.2.13)$$

and the Discharging Rate (DR) (veh/hr) is:

$$DR = -\frac{dn}{dt} = \left(C \times N_{i_b} - \bar{q}_{i_u} \times N_{i_u} + W_d \times \bar{K}_{i_u} \times N_{i_u}\right) \qquad (3.2.14)$$

Step 2'

The number of vehicles that left the queue in this update cycle is calculated as

$$Q'_{n'} = DR \times \Delta t_{n'} \text{ for } n' = 1,2,3...m' \qquad (3.2.15)$$

`where n' is the number of update cycles under the queue discharge case. m' is reached when the queue is dissipated totally.

The total number of vehicles discharged to the current instant of time is determined using the equation

$$Q'_{m'} = \sum_{n'=1}^{m'} Q'_{n'} \qquad (3.2.16)$$

Step 3'

The number of vehicles remaining in the queue is given by $Q_m - Q'_{m'}$ where, Q_m is the number of vehicles in the queue when approaching flow fell below the bottleneck capacity.

Therefore the travel time in queue for a vehicle entering the queue now would be

$$tt'_{b_{n'}} = \frac{Q_m - Q'_{m'}}{C \times N_{i_b}} \text{; for } n' = 1, 2, 3\ldots m' \qquad (3.2.17)$$

Step 4'

The queue length is determined again for each step as follows:

$$QL' = \frac{Q_m - Q'_{m'}}{\overline{K}_{i_b} \times N_{i_u}} \tag{3.2.18}$$

The conditions for $QL' \geq l_u$ from Step 4 also hold true here correspondingly. The flows and densities from the link on which the back of the queue lies are utilized for travel time calculation.

Step 5'

The total travel time TT'_i in hours is determined

If $QL' \leq l_u$; then

$$TT'_i = (l_u - QL') \Big/ \frac{\overline{q}_{i_u}}{\overline{K}_{i_u}} + tt'_{b_{n'}} + l_d \Big/ \frac{\overline{q}_{i_d}}{\overline{K}_{i_d}} \tag{3.2.19}$$

The procedure is similar to Step 5 of queue building case.

If $QL' > l_u$

$$TT'_i = tt'_{b_{n'}} \times \frac{l_u}{QL'} + l_d \Big/ \frac{\overline{q}_{i_d}}{\overline{K}_{i_d}} \tag{3.2.20}$$

Step 6'

Steps 1' to 5' are repeated for the next m' update cycles until

$$Q_m - Q'_{m'} \leq Q'_{n'} \tag{3.2.21}$$

i.e until the queue has totally dissipated. Then, normal travel time estimations are resumed as in no closure and no incident case.

3.2.1 EXAMPLE FOR USE OF CASE A ALGORITHM

The bottleneck algorithm is explained by means of an example. A freeway segment similar to the one shown in Figure: Bottleneck is considered. The freeway had three lanes but one of the lanes is closed for a distance of 1mile for repair. The length of the link in consideration is 6 miles and the bottleneck starts at the center of the link. Only two lanes are available for traffic for 1 mile starting at the center of the freeway. After this 1mile stretch of bottleneck, the number of lanes again increases to 3. The bottleneck capacity is assumed to be 2000 vphpl. As long as the upstream flow is less than the bottleneck capacity of 2 X 2000 ie 4000 vphph, there will not be queuing on the freeway. Once the upstream flow exceeds the capacity, a shockwave will be formed on the freeway. It is assumed that density in queue at the bottleneck is 120 vpmpl. The link i being 6 miles long, the upstream and downstream sections are assumed to be l_u = 3 miles =l_d. The flows averaged to 5 minutes at the detectors are assumed to be as shown in Table3.2.1: Flows and densities at the bottleneck, where,

Time → Time of day (AM)
n → Number of update cycle
t → Time from start of the inception of bottleneck algorithm
q u → Upstream flow at the start of the queue in vehicles per hour per lane (vphpl)
k u → Upstream density measured in Vehicles per mile per lane (vpmpl)
C → Capacity of the Bottleneck
K b → Queue density (Just before the bottleneck section)
q d → Downstream flow in vehicles per hour per lane (vphpl)
k d→ Downstream density measured in vehicles per mile per lane (vpmpl)

Time	n	t	q u	k u	C	k b	q d	k d
7:30	0	0	1400	25.45	2000	120	1333	24.24
	1	5	1500	27.27	2000	120	1333	24.24
	2	10	1600	29.09	2000	120	1333	24.24
	3	15	1700	30.91	2000	120	1333	24.24
	4	20	1800	32.73	2000	120	1333	24.24
	5	25	1900	34.55	2000	120	1333	24.24
8:00	6	30	2000	36.36	2000	120	1333	24.24
	7	35	2000	36.36	2000	120	1333	24.24
	8	40	2000	36.36	2000	120	1333	24.24
	9	45	2000	36.36	2000	120	1333	24.24
	10	50	2000	36.36	2000	120	1333	24.24
	11	55	1900	34.55	2000	120	1333	24.24
8:30	12	60	1900	34.55	2000	120	1333	24.24
	13	65	1800	32.73	2000	120	1333	24.24
	14	70	1800	32.73	2000	120	1333	24.24
	15	75	1700	30.91	2000	120	1333	24.24
	16	80	1600	29.09	2000	120	1333	24.24
	17	85	1500	27.27	2000	120	1333	24.24
9:00	18	90	1400	25.45	2000	120	1333	24.24
	19	95	1300	23.64	2000	120	1333	24.24
	20	100	1200	21.82	2000	120	1333	24.24
	21	105	1200	21.82	2000	120	1333	24.24
	22	110	1200	21.82	2000	120	1333	24.24
	23	115	1100	20	2000	120	1333	24.24
9:30	24	120	1000	18.18	2000	120	1333	24.24
	25	125	1000	18.18	2000	120	1333	24.24
	26	130	1000	18.18	2000	120	1333	24.24
	27	135	1000	18.18	2000	120	1333	24.24
	28	140	1000	18.18	2000	120	1333	24.24
	29	145	1000	18.18	2000	120	1333	24.24
10:00	30	150	1000	18.18	2000	120	1333	24.24
	31	155	1000	18.18	2000	120	1333	24.24
	32	160	1000	18.18	2000	120	1333	24.24
	33	165	1000	18.18	2000	120	1333	24.24
	34	170	1000	18.18	2000	120	1333	24.24
	35	175	1000	18.18	2000	120	1333	24.24
10:30	36	180	1000	18.18	2000	120	1333	24.24
	37	185	1000	18.18	2000	120	1333	24.24
	38	190	1000	18.18	2000	120	1333	24.24
	39	195	1000	18.18	2000	120	1333	24.24
	40	200	1000	18.18	2000	120	1333	24.24
	41	205	1000	18.18	2000	120	1333	24.24
11:00	42	210	1000	18.18	2000	120	1333	24.24
	43	215	1000	18.18	2000	120	1333	24.24
	44	220	1000	18.18	2000	120	1333	24.24
	45	225	1000	18.18	2000	120	1333	24.24
	46	230	1000	18.18	2000	120	1333	24.24
	47	235	1000	18.18	2000	120	1333	24.24
11:30	48	240	1000	18.18	2000	120	1333	24.24
	49	245	1000	18.18	2000	120	1333	24.24
	50	250	1000	18.18	2000	120	1333	24.24

Table3.2.1: Flows and densities at the bottleneck

*Note that the upstream flow 3 X1400 =4200 vph at time t_0 is greater than downstream flow of 2 *2000 = 4000 and hence we can start using the bottleneck algorithm here

Step 1

The backward forming shock-wave velocity is determined first in (mph).

$$W_u = \frac{(\overline{q}_{i_u} \times N_{i_u} - C \times N_{i_b})/N_{i_u}}{\overline{K}_{i_u} - \overline{K}_{i_b}}$$

W_u = (1400 X 3 – 2000 X 2)/3 X (25.45 – 120) = -0.705 mph

Then the Queuing Rate (QR) (veh/hr) is:

$$QR = \frac{dn}{dt} = \left(\overline{q}_{i_u} \times N_{i_u} - C \times N_{i_b} - W_u \times \overline{K}_{i_u} \times N_{i_u}\right)$$

= (1400 X 3 – 2000 X 2 + 0.705 X 25.45 X 3) = 253.8 vph

Step 2

The number of vehicles queuing by time $(t_0 + n\Delta t)$ where Δt =5 min is

$Q_n = QR \times \Delta t_n$ = 253.8 * 5/60 = 21.55 vehilces

The total number of vehicles in queue is found using the following expression.

$$Q_m = \sum_{n=1}^{m} Q_n = 21.55 \text{ vehicles}$$

Step 3

Now, the travel time $\left(\overline{tt}_{b_n}\right)$ in hours in the queue is determined.

$$\overline{tt}_{b_n} = \frac{Q_m}{C \times N_{i_b}} = 21.55/\ (2000 \text{ X } 2 \text{ X } 2) = 0.005 \text{ hrs}$$

Step 4

Queue Length (QL) in miles from the start of the bottleneck is:

$$QL = \frac{Q_m}{\overline{K}_{i_b} \times N_{i_u}} = 21.55/(120*3) = 0.059 \text{ mi}$$

Step 5

The average travel time (TT_i) in hours on the link (i) is now determined.

$$TT_i = \left(l_u - QL\right) \Big/ \frac{\overline{q}_{i_u}}{\overline{K}_{i_u}} + \overline{tt}_{b_n} + l_d \Big/ \frac{\overline{q}_{i_d}}{\overline{K}_{i_d}}$$

= 60 X[(3-0.059)/(1400/25.45) + 0.005 + 3.0 / (1333/24.24)]

= 6.799 min

It is observed that upstream flow is greater than the bottleneck discharge for the next update cycle too. The travel time estimation process is repeated now for the next update cycle.

Step 1

W_u = (1500 X 3 – 2000 X 2)/ 3 X (27.27 – 120) = -1.797 mph

Then the Queuing Rate (QR) (veh/hr) is:

$$QR = \frac{dn}{dt} = \left(\overline{q}_{i_u} \times N_{i_u} - C \times N_{i_b} - W_u \times \overline{K}_{i_u} \times N_{i_u}\right)$$

= (1500 X 3 – 2000 X 2 + 1.797 X 27.27 X 3) = 647.1 vph

Step 2

The number of vehicles queuing by time $(t_0 + n\Delta t)$ where Δt =5 min is

$Q_2 = QR \times \Delta t_n$ = 647.1 * 5/60 = 53.92 vehilces

The total number of vehicles in queue is

$$Q_m = \sum_{n=1}^{m} Q_n$$ =21.55 + 53.92 = 75.08 vehicles

Step 3

Now, the travel time $\left(\overline{tt}_{b_n}\right)$ in hours in the queue is determined.

$$\overline{tt}_{b_n} = \frac{Q_m}{C \times N_{i_b}}$$ = 75.08/ (2000 X 2) = 0.019 hrs

Step 4

Queue Length (QL) in miles from the start of the bottleneck:

$$QL = \frac{Q_m}{\overline{K}_{i_b} \times N_{i_u}}$$ = 75.08/(120*3) = 0.209 mi

Step 5

The travel time (TT_i) in hours on the link (i) is now determined for this cycle.

$$TT_i = \left(l_u - QL\right) \bigg/ \frac{\overline{q}_{i_u}}{\overline{K}_{i_u}} + \overline{tt}_{b_n} + l_d \bigg/ \frac{\overline{q}_{i_d}}{\overline{K}_{i_d}}$$

= 60 X[(3-0.209)/(1500/27.27) + 0.019 + 3.0 / (1333/24.24)]

= 7.444 min

The process is repeated now for the next update cycle again as long as the upstream flow is greater than the bottleneck discharge. When the length of the queue exceeds the length

l_u the queue spills into link (i-1). The flows and densities from detector (i-1) are used as upstream flows and densities in this case. If there is no detector on link (i-1) the historical flow values for this link are used as upstream flows and densities. The case where the queue length is greater than l_u is shown here. The update cycle considered here is t_7 i.e at 8:05 AM.

Step 1

W_u = (2000 X 3 – 2000 X 2)/(3 X (36.36– 120)) = -7.971 mph

Then the Queuing Rate (QR) (veh/hr) is:

$$QR = \frac{dn}{dt} = \left(\bar{q}_{i_u} \times N_{i_u} - C \times N_{i_b} - W_u \times \bar{K}_{i_u} \times N_{i_u}\right)$$

= (2000 X 3 – 2000 X 2 + 7.971 X 36.36 X 3) = 2870 vph

Step 2

The number of vehicles queuing by time $(t_0 + n\Delta t)$ where Δt =5 min is

$Q_7 = QR \times \Delta t_n$ = 2870 * 5/60 = 239.1 vehilces

The total number of vehicles in queue is found using the following expression.

$$Q_m = \sum_{n=1}^{m} Q_n$$ = 1124 vehicles

Step 3

Now, the travel time $\left(\bar{tt}_{b_n}\right)$ in hours in the queue is determined.

$$\bar{tt}_{b_n} = \frac{Q_m}{C \times N_{i_b}}$$ = 1124 / (2000 X 2) = 0.281 hrs

Step 4

Queue Length (QL) in miles from the start of the bottleneck:

$$QL = \frac{Q_m}{\bar{K}_{i_b} \times N_{i_u}}$$ = 1124 /(120*3) = 3.123 mi

Step 5

The travel time (TT_i) in hours on the link (i) is now determined for this cycle.

$$TT_i = \bar{tt}_{b_n} \times \frac{l_u}{QL} + l_d \bigg/ \frac{\bar{q}_{i_d}}{\bar{K}_{i_d}}$$

= 60 X [0.281 X 3 / 3.123 mi + 3.0 / (1333 / 24.24)] = 19.47 min

The process is repeated till update cycle t_{19}. In cycle t_{19} it can seen that the upstream flow of 1300 X 3 = 3900 vph is less than the bottleneck capacity. Hence, the queue will start to dissipate and a forward moving shockwave will be established. The queue dissipation algorithm is now used to calculate travel times on the link i.

Step 1’

Speed of forward moving shockwave is now,

$$W_d = \frac{\left(C \times N_{i_b} - \bar{q}_{i_u} \times N_{i_u}\right) / N_{i_u}}{\bar{K}_{i_b} - \bar{K}_{i_u}} = (2000 \text{ X } 2 - 1300 \text{ X } 3) /3 \text{ X } (120 - 23.64) =$$

0.346mph

and the Discharging Rate (DR) (veh/hr) is:

$$DR = -\frac{dn}{dt} = \left(C \times N_{i_b} - \bar{q}_{i_u} \times N_{i_u} + W_d \times \bar{K}_{i_u} \times N_{i_u}\right)$$

$$= (2000 \text{ X } 2 - 1000 \text{ X } 3 + 0.346 \text{ X } 23.64 \text{ X } 3) = 124.5 \text{ vph}$$

Step 2’

$Q'_{n'} = DR \times \Delta t_{n'} = 10.38$ vehicles

The total number of vehicles discharged to the current instant of time is determined using the equation

$$Q'_{m'} = \sum_{n'=1}^{m'} Q'_{n'} = 10.38$$

Step 3’

The number of vehicles remaining in the queue is given by $Q_m - Q'_{m'}$ Therefore the travel time in the queue would be

$$tt'_{b_{n'}} = \frac{Q_m - Q'_{m'}}{\bar{q}_{i_b} \times N_{i_b}} = (2847 - 10.38)/ (2000 \text{ X } 2) = 0.709 \text{ hrs}$$

where Q_m is the number of vehicles in the queue when approaching flow exceeded the bottleneck flow.

Step 4’

The queue length is determined again for each step as follows:

$$QL' = \frac{Q_m - Q'_{m'}}{\bar{K}_{i_b} \times N_{i_u}} = (2847 - 10.38)/ (120 \text{ X } 3) = 7.879 \text{ mi}$$

The flows and densities from the link corresponding to the start of this queue are used in estimating travel times. Here they are assumed to be flows and densities shown in the Table: Flows and Densities at the bottleneck.

Step 5'

The average travel time on link i for update cycle t_{19} is

$$TT_i = \overline{tt}_{b_n} \times \frac{l_u}{QL} + l_d \Big/ \frac{\overline{q}_{i_d}}{\overline{K}_{i_d}}$$ = (0.709X 3.0/10.15 + 3.0 X 24.4 / 1333) = 19.47 min

Step 6'

The steps 1' to 5' are repeated until

$$Q_m - Q'_{m'} \leq Q'_{n'}$$

The calculations for last update cycle are shown now:

Step 1'

$$W_d = \frac{\left(C \times N_{i_b} - \overline{q}_{i_u} \times N_{i_u}\right)/N_{i_u}}{\overline{K}_{i_b} - \overline{K}_{i_u}}$$ = (2000 X 2 – 1000 X 3) / 3 X (120 – 18.18) = 3.274 mph

and the Discharging Rate (DR) (veh/hr) is:

$$DR = -\frac{dn}{dt} = \left(C \times N_{i_b} - \overline{q}_{i_u} \times N_{i_u} + W_d \times \overline{K}_{i_u} \times N_{i_u}\right)$$

= (2000 X 2 – 1000 X 3 + 3.274 X 18.18 X 3) = 1179 vph

Step 2'

$Q'_{n'} = DR \times \Delta t_{n'}$ = 98.21 vehicles

The total number of vehicles discharged to the current instant of time is determined using the equation

$$Q'_{m'} = \sum_{n'=1}^{m'} Q'_{n'}$$ = 2756.37

Step 3'

The average travel time in the queue would be

$$tt'_{b_{n'}} = \frac{Q_m - Q'_{m'}}{\overline{q}_{i_b} \times N_{i_b}}$$ = 90.63/ (2000 X 2) = 0.023 hrs

where Q_m is the number of vehicles in the queue when approaching flow fell below the bottleneck capacity.

Step 4'

The queue length is determined again for each step as follows:

$$QL' = \frac{Q_m - Q'_{m'}}{\bar{K}_{i_b} \times N_{i_u}} = 90.63/(120 \text{ X } 3) = 0.252 \text{ mi}$$

Step 5'

The average travel time on link i for this update cycle is

$$TT'_i = \left(l_u - QL'\right) \Big/ \frac{\bar{q}_{i_u}}{\bar{K}_{i_u}} + tt'_{b_{n'}} + l_d \Big/ \frac{\bar{q}_{i_d}}{\bar{K}_{i_d}}$$

= 60 X(3.0-0.252) X 18.18/1000 + 60 X 0.023 + 60 X 3.0 X 24.24/1333

= 7.63 min

Since $Q_m - Q'_{m'} \le Q'_{n'}$, the queue will be totally dissipated in this cycle and the end of bottleneck algorithm is reached. The calculations of travel times are now carried on using the no incident no closure case algorithm. A summary of calculations for the above example is provided below.

Travel Time Estimation under Lane Closure

lu	3	ld	3
N iu	3	Nib	2

Time	n	t	q u	k u(55)	C	k b	q d	k d(55)
7:30	0	0	1400	25.45	2000	120	1333	24.24
	1	5	1500	27.27	2000	120	1333	24.24
	2	10	1600	29.09	2000	120	1333	24.24
	3	15	1700	30.91	2000	120	1333	24.24
	4	20	1800	32.73	2000	120	1333	24.24
	5	25	1900	34.55	2000	120	1333	24.24
8:00	6	30	2000	36.36	2000	120	1333	24.24
	7	35	2000	36.36	2000	120	1333	24.24
	8	40	2000	36.36	2000	120	1333	24.24
	9	45	2000	36.36	2000	120	1333	24.24
	10	50	2000	36.36	2000	120	1333	24.24
	11	55	1900	34.55	2000	120	1333	24.24
8:30	12	60	1900	34.55	2000	120	1333	24.24
	13	65	1800	32.73	2000	120	1333	24.24
	14	70	1800	32.73	2000	120	1333	24.24
	15	75	1700	30.91	2000	120	1333	24.24
	16	80	1600	29.09	2000	120	1333	24.24
	17	85	1500	27.27	2000	120	1333	24.24
9:00	18	90	1400	25.45	2000	120	1333	24.24
	19	95	1300	23.64	2000	120	1333	24.24
	20	100	1200	21.82	2000	120	1333	24.24
	21	105	1200	21.82	2000	120	1333	24.24
	22	110	1200	21.82	2000	120	1333	24.24
	23	115	1100	20	2000	120	1333	24.24
9:30	24	120	1000	18.18	2000	120	1333	24.24
	25	125	1000	18.18	2000	120	1333	24.24
	26	130	1000	18.18	2000	120	1333	24.24
	27	135	1000	18.18	2000	120	1333	24.24
	28	140	1000	18.18	2000	120	1333	24.24
	29	145	1000	18.18	2000	120	1333	24.24
10:00	30	150	1000	18.18	2000	120	1333	24.24
	31	155	1000	18.18	2000	120	1333	24.24
	32	160	1000	18.18	2000	120	1333	24.24
	33	165	1000	18.18	2000	120	1333	24.24
	34	170	1000	18.18	2000	120	1333	24.24
	35	175	1000	18.18	2000	120	1333	24.24
10:30	36	180	1000	18.18	2000	120	1333	24.24

w	QR	Qn	Qm	ttbn	QL	Tti	Tti(mins)
-0.705	253.8	21.15	21.15	0.005	0.059	0.113	6.79866
-1.797	647.1	53.92	75.08	0.019	0.209	0.124	7.44408
-2.933	1056	88	163.1	0.041	0.453	0.142	8.49742
-4.116	1482	123.5	286.5	0.072	0.796	0.166	9.97531
-5.347	1925	160.4	447	0.112	1.242	0.198	11.8954
-6.631	2387	198.9	645.9	0.161	1.794	0.238	14.2767
-7.971	2870	239.1	885	0.221	2.458	0.286	17.139
-7.971	2870	239.1	1124	0.281	3.123	0.325	19.4727
-7.971	2870	239.1	1363	0.341	3.787	0.325	19.4727
-7.971	2870	239.1	1602	0.401	4.451	0.325	19.4727
-7.971	2870	239.1	1842	0.46	5.115	0.325	19.4727
-6.631	2387	198.9	2040	0.51	5.668	0.325	19.4727
-6.631	2387	198.9	2239	0.56	6.221	0.325	19.4727
-5.347	1925	160.4	2400	0.6	6.666	0.325	19.4727
-5.347	1925	160.4	2560	0.64	7.112	0.325	19.4727
-4.116	1482	123.5	2684	0.671	7.455	0.325	19.4727
-2.933	1056	88	2772	0.693	7.699	0.325	19.4727
-1.797	647.1	53.92	2826	0.706	7.849	0.325	19.4727
-0.705	253.8	21.15	2847	0.712	7.908	0.325	19.4727
0.346	-124.5	-10.38	2836	0.709	7.879	0.325	19.4727
1.358	-488.9	-40.74	2796	0.699	7.766	0.325	19.4727
1.358	-488.9	-40.74	2755	0.689	7.653	0.325	19.4727
1.358	-488.9	-40.74	2714	0.679	7.539	0.325	19.4727
2.333	-840	-70	2644	0.661	7.345	0.325	19.4727
3.274	-1179	-98.21	2546	0.636	7.072	0.325	19.4727
3.274	-1179	-98.21	2448	0.612	6.799	0.325	19.4727
3.274	-1179	-98.21	2350	0.587	6.527	0.325	19.4727
3.274	-1179	-98.21	2251	0.563	6.254	0.325	19.4727
3.274	-1179	-98.21	2153	0.538	5.981	0.325	19.4727
3.274	-1179	-98.21	2055	0.514	5.708	0.325	19.4727
3.274	-1179	-98.21	1957	0.489	5.435	0.325	19.4727
3.274	-1179	-98.21	1858	0.465	5.162	0.325	19.4727
3.274	-1179	-98.21	1760	0.44	4.89	0.325	19.4727
3.274	-1179	-98.21	1662	0.416	4.617	0.325	19.4727
3.274	-1179	-98.21	1564	0.391	4.344	0.325	19.4727
3.274	-1179	-98.21	1466	0.366	4.071	0.325	19.4727
3.274	-1179	-98.21	1367	0.342	3.798	0.325	19.4727

	37	185	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	1269	0.317	3.526	0.325	19.47
	38	190	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	1171	0.293	3.253	0.325	19.47
	39	195	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	1073	0.268	2.98	0.323	19.39
	40	200	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	974.6	0.244	2.707	0.304	18.21
	41	205	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	876.3	0.219	2.434	0.284	17.04
11:00	42	210	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	778.1	0.195	2.161	0.264	15.86
	43	215	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	679.9	0.17	1.889	0.245	14.68
	44	220	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	581.7	0.145	1.616	0.225	13.51
	45	225	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	483.5	0.121	1.343	0.206	12.33
	46	230	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	385.3	0.096	1.07	0.186	11.16
	47	235	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	287.1	0.072	0.797	0.166	9.981
11:30	48	240	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	188.8	0.047	0.525	0.147	8.806
	49	245	1000	18.18	2000	120	1333	24.24	3.274	-1179	-98.21	90.63	0.023	0.252	0.127	7.63

Table 3.2.2: Travel Time Estimation under Lane closure case with 1 lane closed

w → Shockwave Speed

QR→ Queuing or Dissipation rate

Qn → Number of vehicles added or removed from queue in time interval t_n

Q_m→ The total number of vehicles that are in queue.

Ttbn→ Average Travel time in queue

QL → Queue Length in miles

TTi → Average Travel Time on link i in hours. (Including upstream and downstream sections)

TTi (mins)→ Average Travel Time on link i in minutes. (Including upstream and downstream sections)

The algorithm is similar under incident conditions. The only difference is that when the incident is cleared, the number of lanes at the bottleneck increases. Consider a case where the incident occurs at 7:25 AM on a 3 lane freeway blocking one lane. The incident is cleared at 8:15 AM removing the block and making all three lanes available. The bottleneck algorithm would be used in this case as shown below.

Travel Time Estimation under Incident Conditions

Incident occurs at 7:25 and is cleared by 8:15

lu	3	ld	3		
N iu	3	Nib1	2	Nib2	3

Time	n	t	q u	k u	C	k b	q d	k d
7:30	0	0	1400	25.45	2000	120	1333	24.24
7:35	1	5	1500	27.27	2000	120	1333	24.24
7:40	2	10	1600	29.09	2000	120	1333	24.24
7:45	3	15	1700	30.91	2000	120	1333	24.24
7:50	4	20	1800	32.73	2000	120	1333	24.24
7:55	5	25	1900	34.55	2000	120	1333	24.24
8:00	6	30	2000	36.36	2000	120	1333	24.24
8:05	7	35	2000	36.36	2000	120	1333	24.24
8:10	8	40	2000	36.36	2000	120	1333	24.24
8:15	9	45	2000	36.36	2000	120	1333	24.24
8:20	10	50	2000	36.36	2000	120	2000	36.36
8:25	11	55	1900	34.55	2000	120	2000	36.36
8:30	12	60	1900	34.55	2000	120	2000	36.36
8:35	13	65	1800	32.73	2000	120	2000	36.36
8:40	14	70	1800	32.73	2000	120	2000	36.36
8:45	15	75	1700	30.91	2000	120	2000	36.36
8:50	16	80	1600	29.09	2000	120	2000	36.36
8:55	17	85	1500	27.27	2000	120	2000	36.36
9:00	18	90	1400	25.45	2000	120	2000	36.36
9:05	19	95	1300	23.64	2000	120	2000	36.36
9:10	20	100	1200	21.82	2000	120	2000	36.36
9:15	21	105	1200	21.82	2000	120	2000	36.36

w	QR	Qn	Qm	ttbn	QL	Tti	Tti(mins)
-0.705	253.8	21.15	21.15	0.005	0.059	0.113	6.799
-1.797	647.1	53.92	75.08	0.019	0.209	0.124	7.444
-2.933	1056	88	163.1	0.041	0.453	0.142	8.497
-4.116	1482	123.5	286.5	0.072	0.796	0.166	9.975
-5.347	1925	160.4	447	0.112	1.242	0.198	11.9
-6.631	2387	198.9	645.9	0.161	1.794	0.238	14.28
-7.971	2870	239.1	885	0.221	2.458	0.286	17.14
-7.971	2870	239.1	1124	0.281	3.123	0.325	19.47
-7.971	2870	239.1	1363	0.341	3.787	0.325	19.47
-7.971	2870	239.1	1602	0.401	4.451	0.325	19.47
0	0	0	1602	0.267	4.451	0.235	14.07
1.17	-421.3	-35.11	1567	0.261	4.354	0.235	14.07
1.17	-421.3	-35.11	1532	0.255	4.256	0.235	14.07
2.292	-825	-68.75	1463	0.244	4.065	0.235	14.07
2.292	-825	-68.75	1395	0.232	3.874	0.235	14.07
3.367	-1212	-101	1294	0.216	3.594	0.235	14.07
4.4	-1584	-132	1162	0.194	3.227	0.235	14.07
5.392	-1941	-161.8	999.9	0.167	2.778	0.225	13.51
6.346	-2285	-190.4	809.5	0.135	2.249	0.203	12.19
7.264	-2615	-217.9	591.6	0.099	1.643	0.178	10.67
8.148	-2933	-244.4	347.2	0.058	0.964	0.149	8.965
8.148	-2933	-244.4	102.7	0.017	0.285	0.121	7.261

Table 3.2.3: Travel Time Estimation under Incident Condition with 1 lane closed

Nib1 → Number of lanes available when the incident occurs; Nib2 → Number of lanes available when the incident is cleared.(At 8:15 am) This value will be used from update cycle 10 (ending 8:20)

Another variant of this algorithm is when more than one lane is blocked due to the incident on a freeway and one lane is opened at each step. For example, consider a case where an incident occurs at 7:25 AM on a three-lane freeway and one lane is opened at 8:00 AM while the other lane is opened at 8:30 AM. The bottleneck algorithm would work as shown below.

Travel Time Estimation under Incident conditions

Incident occurs at 7:30 and two lanes are blocked. One lane is opened at 8:00 and the other at 8:30

lu	3	ld	3	l(i-1)	6		
N iu	3	Nib1	1	Nib2	2	Nib3	3

Time	n	t	q u	k u	C	k b	q d	k d
7:30	0	0	1400	25.45	2000	120	666.7	12.12
	1	5	1500	27.27	2000	120	666.7	12.12
	2	10	1600	29.09	2000	120	666.7	12.12
	3	15	1700	30.91	2000	120	666.7	12.12
	4	20	1800	32.73	2000	120	666.7	12.12
	5	25	1900	34.55	2000	120	666.7	12.12
8:00	6	30	2000	36.36	2000	120	666.7	12.12
	7	35	2000	36.36	2000	120	1333	24.24
	8	40	2000	36.36	2000	120	1333	24.24
	9	45	2000	36.36	2000	120	1333	24.24
	10	50	2000	36.36	2000	120	1333	24.24
	11	55	1900	34.55	2000	120	1333	24.24
8:30	12	60	1900	34.55	2000	120	1333	24.24
	13	65	1800	32.73	2000	120	2000	36.36
	14	70	1800	32.73	2000	120	2000	36.36
	15	75	1700	30.91	2000	120	2000	36.36
	16	80	1600	29.09	2000	120	2000	36.36
	17	85	1500	27.27	2000	120	2000	36.36
9:00	18	90	1400	25.45	2000	120	2000	36.36
	19	95	1300	23.64	2000	120	2000	36.36
	20	100	1200	21.82	2000	120	2000	36.36
	21	105	1200	21.82	2000	120	2000	36.36
	22	110	1200	21.82	2000	120	2000	36.36
	23	115	1100	20	2000	120	2000	36.36
9:30	24	120	1000	18.18	2000	120	2000	36.36
	25	125	1000	18.18	2000	120	2000	36.36

w	QR	Qn	Qm	ttbn	QL	Tti	Tti(mins)
-7.756	2792	232.7	232.7	0.116	0.646	0.214	12.8211
-8.987	3235	269.6	502.3	0.251	1.395	0.335	20.0923
-10.27	3696	308	810.3	0.405	2.251	0.473	28.399
-11.6	4176	348	1158	0.579	3.217	0.595	35.6727
-12.99	4675	389.6	1548	0.774	4.3	0.595	35.6727
-14.43	5196	433	1981	0.99	5.502	0.595	35.6727
-15.94	5739	478.3	2459	1.23	6.831	0.595	35.6727
-7.971	869.6	72.46	2532	0.422	7.032	0.235	14.0727
-7.971	869.6	72.46	2604	0.434	7.233	0.235	14.0727
-7.971	869.6	72.46	2676	0.446	7.435	0.235	14.0727
-7.971	869.6	72.46	2749	0.458	7.636	0.235	14.0727
-6.631	387.2	32.27	2781	0.464	7.726	0.235	14.0727
-6.631	387.2	32.27	2813	0.469	7.815	0.235	14.0727
2.292	-825	-68.75	2745	0.457	7.624	0.235	14.0727
2.292	-825	-68.75	2676	0.446	7.433	0.235	14.0727
3.367	-1212	-101	2575	0.429	7.153	0.235	14.0727
4.4	-1584	-132	2443	0.407	6.786	0.235	14.0727
5.392	-1941	-161.8	2281	0.38	6.337	0.235	14.0727
6.346	-2285	-190.4	2091	0.348	5.808	0.235	14.0727
7.264	-2615	-217.9	1873	0.312	5.202	0.235	14.0727
8.148	-2933	-244.4	1628	0.271	4.523	0.235	14.0727
8.148	-2933	-244.4	1384	0.231	3.844	0.235	14.0727
8.148	-2933	-244.4	1140	0.19	3.165	0.235	14.0727
9	-3240	-270	869.5	0.145	2.415	0.21	12.6059
9.821	-3536	-294.6	574.9	0.096	1.597	0.176	10.5524
9.821	-3536	-294.6	280.3	0.047	0.779	0.142	8.4988

Table 3.2.4: Travel Time Estimation under Incident Condition with 2 lanes closed

3.3 CASE B: TRAVEL TIME ESTIMATION ALGORITHM UNDER INCIDENT CONDITIONS

Case A presented the travel time estimation algorithm under lane closures. When there is an incident on a freeway causing a lane closure, a similar algorithm will be utilized for travel time estimation, as the situation is similar in nature. The only difference is that when the lane opened for traffic after the incident is cleared, the queue dissipates at a faster rate. In order to extend the Case A algorithm for travel time estimation to cases when there are incidents on freeways it is important to know when the incident occurred, and when the incident will be cleared. The time the incident is cleared will depend on the characteristics of the incident.

In order to calculate travel times during incident conditions, an algorithm was developed which is based on the Case A algorithm. This algorithm is called the 'Case B' algorithm or 'incident algorithm'. The algorithm has six steps:

A- Determining incident characteristics, severity, link location (upstream and downstream sensors), reported occurrence time ($t_{i\,(r)}$), weather, and responding emergency personnel from media and external data sources.

B- Using the information in A and the upstream and downstream sensor data to determine the actual occurrence time of the incident ($t_{i(a)}$)

C- From A and B above, determining the time the incident will be cleared. (t_{CT})

D- Determining the emergency response time ($t_{(e)}$)

E- Calculating and updating the travel time on the affected upstream links using the information from A, B, C and D for each time interval between ($t_{i(a)}$) and ($t_{(e)}$+t_{CT})

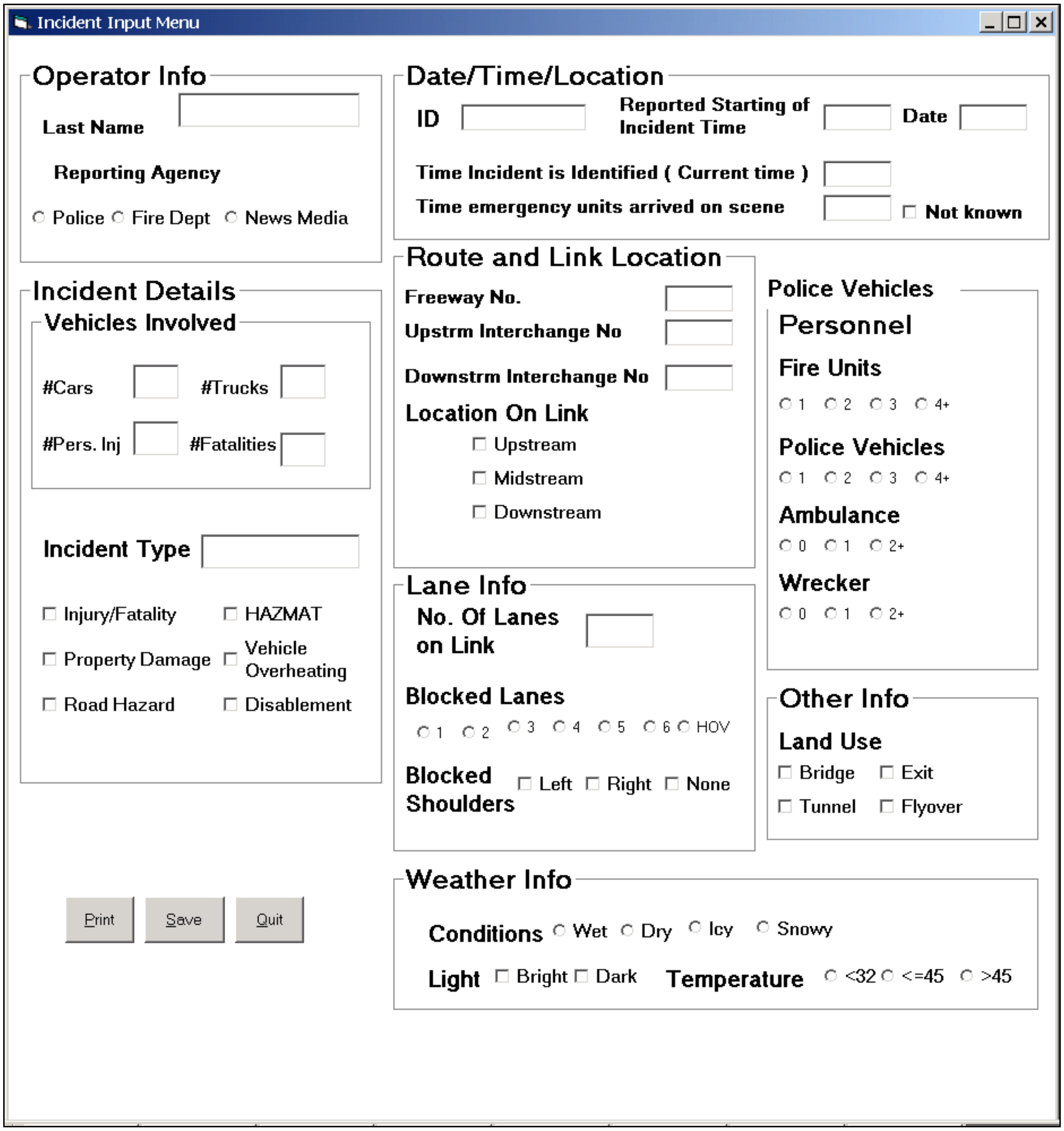
F- Once incident is cleared, calculating and updating the travel time on the affected upstream links for each time interval between ($t_{(e)}$+t_{CT}) and the time needed to reach normal flow (NF) defined as (t_{CT} + t_{NF}).

A description of the various steps in this algorithm is provided below.

3.3.1 A - INCIDENT INPUT DATA

Once the incident is reported and verified (referred to as initial status), the incident data to be collected by the operator is shown in Figure 3.3.1. The data includes information on operator who is entering the data, incident type, vehicles involved, location on route and on link, blocked lanes and shoulders, weather conditions, date and time of occurrence, emergency and response personnel and vehicles, and other information related to land use.

Part of this information is updated every five minutes or when new information is obtained, in order to document the current status of the incident, and fed back to the travel time estimation algorithm, as shown in Figure 3.3.2.



Incident Input Menu

Operator Info

Last Name ☐

Reporting Agency

○ Police ○ Fire Dept ○ News Media

Date/Time/Location

ID ☐ **Reported Starting of Incident Time** ☐ **Date** ☐

Time Incident is Identified (Current time) ☐

Time emergency units arrived on scene ☐ ☐ **Not known**

Incident Details

Vehicles Involved

#Cars ☐ #Trucks ☐

#Pers. Inj ☐ #Fatalities ☐

Incident Type ☐

☐ Injury/Fatality ☐ HAZMAT

☐ Property Damage ☐ Vehicle Overheating

☐ Road Hazard ☐ Disablement

Route and Link Location

Freeway No. ☐

Upstrm Interchange No ☐

Downstrm Interchange No ☐

Location On Link

☐ Upstream

☐ Midstream

☐ Downstream

Police Vehicles

Personnel

Fire Units

○ 1 ○ 2 ○ 3 ○ 4+

Police Vehicles

○ 1 ○ 2 ○ 3 ○ 4+

Ambulance

○ 0 ○ 1 ○ 2+

Wrecker

○ 0 ○ 1 ○ 2+

Lane Info

No. Of Lanes on Link ☐

Blocked Lanes

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ HOV

Blocked Shoulders ☐ Left ☐ Right ☐ None

Other Info

Land Use

☐ Bridge ☐ Exit

☐ Tunnel ☐ Flyover

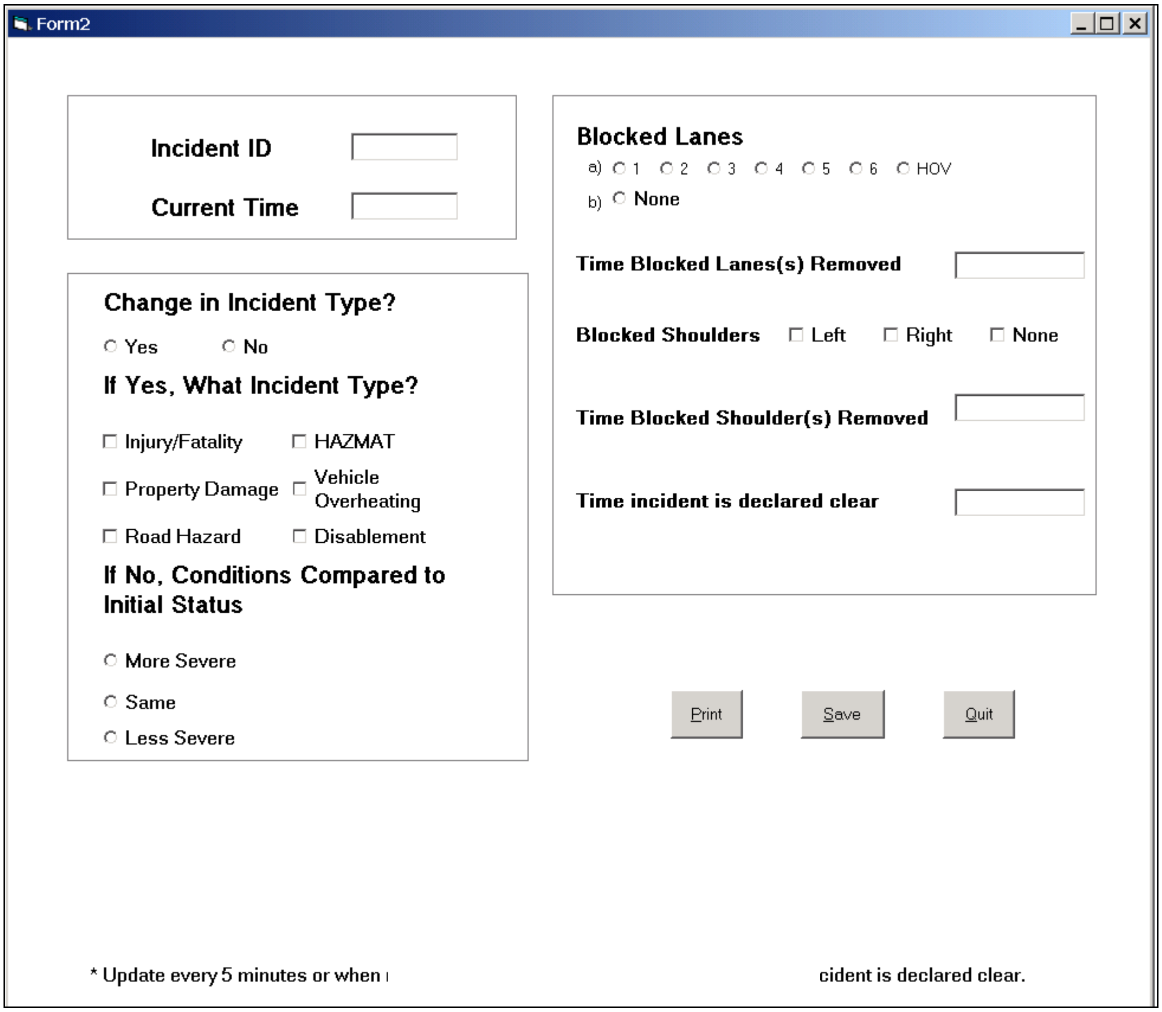
Weather Info

Conditions ○ Wet ○ Dry ○ Icy ○ Snowy

Light ☐ Bright ☐ Dark **Temperature** ○ <32 ○ <=45 ○ >45

Print Save Quit

Figure 3.3.1 Incident Input Menu (Initial Status)



Incident ID ☐

Current Time ☐

Change in Incident Type?

○ Yes ○ No

If Yes, What Incident Type?

☐ Injury/Fatality ☐ HAZMAT

☐ Property Damage ☐ Vehicle Overheating

☐ Road Hazard ☐ Disablement

If No, Conditions Compared to Initial Status

○ More Severe

○ Same

○ Less Severe

Blocked Lanes

a) ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ HOV

b) ○ None

Time Blocked Lanes(s) Removed ☐

Blocked Shoulders ☐ Left ☐ Right ☐ None

Time Blocked Shoulder(s) Removed ☐

Time incident is declared clear ☐

* Update every 5 minutes or when i

cident is declared clear.

Figure 3.3.2 Incident Input Menu (Updated Status)

3.3.2 B- DETERMINING THE INCIDENT OCCURRENCE TIME ($t_{i(a)}$)

The following algorithm is developed to determine the actual occurrence time of an incident, based on the location of the incident, the identified upstream and downstream sensors, and the occupancy data from these detectors for the past hour from the time the incident is reported. ($t_{i(r)}$)

Information is obtained from either operator or road user on the freeway that an incident has occurred. The location of the incident is known but the exact time of the incident is not known. The algorithm described here is used to find the exact time of occurrence of the incident. The structure of the algorithm is presented in Figure 3.3.3. The description of the equations used for this algorithm is shown in Table 1.

It is first checked whether the difference in occupancies of the upstream and downstream detectors at current time t, (OCCDF), is less than 7. If it is not, then, a search is proceeded back in time along the detector data of stations between which the incident has occurred, till detector output is found that matches (OCCDF <7). The first such event is found and the time is noted as $t_{i(a)}$.

When this time $t_{i(a)}$ is found, the next step in the algorithm is executed. It is checked whether the downstream occupancy is decreasing significantly in the time intervals after $t_{i(a)}$, i.e. it is checked if the relative temporal difference in downstream occupancies ($DOCCTD_{5,10}$) is less than or equal to (-0.15) at time ($t_{i(a)}$ + 5) and ($t_{i(a)}$ + 10). If it is not less than or equal to (-0.15), no incident has taken place. It is a false alarm.

If it is less than (-0.15) then the final step to determine the start of the incident is executed. It is checked whether the upstream detector occupancy is going up significantly in the time intervals after $t_{i(a)}$. It is checked if relative temporal difference in upstream occupancies ($UOCCTD_{5,10}$) at ($t_{i(a)}$ + 5) and ($t_{i(a)}$ + 10) is greater than or equal to 0.3. If it is not greater than 0.3, no incident has taken place. If it is greater than 0.3 then the time of occurrence of the incident is $t_{i(a)}$.

The threshold parameters 7, -0.15, 0.3 are determined from accident data obtained by the investigators. However, these values can be changed by the user to fit the urban area under consideration.

Feature	Description	Definition
OCC(i,t)	Occupancy for station i, for time interval t (percent)	
DOCC	Downstream Occupancy	OCC(i+1,t)
OCCDF	Spatial difference in occupancy	OCC(i,t) – OCC(i+1,t)
$DOCCTD_5$	Relative temporal differences in downstream occupancy	[OCC(i +1,t +5) – OCC(i+1,t)]/OCC(i +1,t)
$DOCCTD_{10}$	Relative Temporal Difference in downstream Occupancies	[OCC(i +1,t+10) – OCC(i+1,t)]/OCC(i+1,t)
$UOCCTD_5$	Relative Temporal Difference in upstream Occupancies	[OCC(i,t +5) – OCC(i,t)]/OCC(i,t)
$UOCCTD_{10}$	Relative Temporal Difference in upstream Occupancies	[OCC(i,t +10) – OCC(i,t)]/OCC(i,t)

Table 3.3.1: Description of Equations used for Determining Start Time of Incident

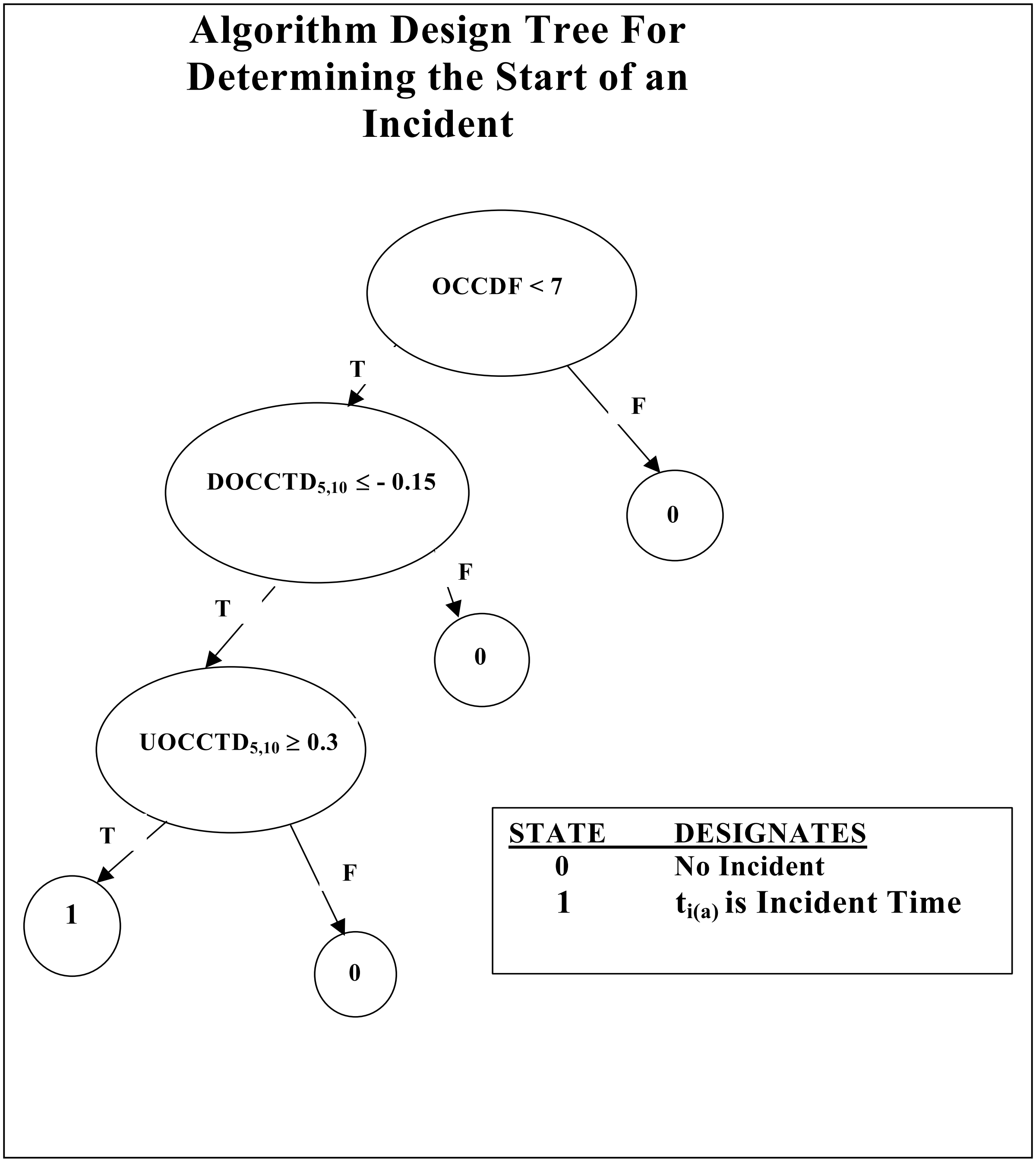


Figure 3.3.3: Algorithm for determining Start Time of Incident

Description of the algorithm for determining start of incident with an example:

	5-min Occupancy at station*						
TIME	21	22	23	24	25	26	27
7:09	15	17	15.4	15	15.8	15.6	15
7:14	16.4	18	17.2	17.2	17.8	16.4	17.8
7:19	16.4	19.6	18.2	20	26.6	13.8	18.2
7:24	14.8	18.8	24.6	39.6	32.6	10.4	10.6
7:29	29.8	25.4	27.2	36	36.4	12.2	11
7:34	29	31.2	32.8	31	28	13.2	13
7:39	36.4	36.8	27.4	32.2	26.4	12.6	13

Note: An incident occurred at 7:15:40 between stations 25 (upstream) and 26(downstream)

*Station indices increase in the direction of travel

Table 3.3.2: Incident on Freeway

The data in Table 3.3.3 shows occupancy values of consecutive detectors on a freeway in Los Angeles averaged to five-minute intervals. The detectors are referenced by a number called 'station index'. The station index increases in the direction of travel. It will be demonstrated here how start time of an incident can be determined from occupancy data.

Information is obtained that an incident has occurred between stations 25 and 26 at some point of time $t_{i\ (r)}$ after the incident has occurred. For this example, it is assumed that this information is obtained at $t_{i\ (r)}$ = 7:25. Proceeding back in the occupancy table, the first point where the occupancy difference is less than 7 is determined. The difference in the occupancy values, OCCDF, between these two stations at 7:14 is (17.8-16.4) = 1.4, which is less than 7. So, we check if the $DOCCTD_5$ and $DOCCTD_{10}$ values are less than –0.15.

$DOCCTD_5 = [OCC(i+1, t+5) – OCC(i+1, t)]/OCC(i+1, t)$

$= (13.8-16.4)/16.4 = -0.158 < -0.15$

$DOCCTD_{10} = [OCC(i+1, t+10) – OCC(i+1, t)]/OCC(i+1, t)$

$= (10.4-16.4)/16.4 = -0.37 < -0.15$

Since the conditions $DOCCTD_{5,10} \leq -0.15$ are satisfied we verify the final condition for the incident i.e. $UOCCTD_{5,10} \geq 0.3$

$UOCCTD_5$ = [OCC(i, t+5) – OCC(i, t)]/OCC(i, t)

= (26.6-17.8)/17.8 = 0.49 > 0.3

$UOCCTD_{10}$ = [OCC(i, t+10) – OCC(i, t)]/OCC(i, t)

= (32.6-17.8)/17.8 = 0.83> 0.3

Since the condition $UOCCTD_{5,10}$ > 0.3 is satisfied, the time of occurrence of the incident is designated as $t_{i\ (a)}$ = 7:14. Note that this is an approximation of the actual time of occurrence of the incident to the nearest 5-minute interval. This approximation is necessary to implement the Case A algorithm for travel time estimation and does not give significant errors in estimates.

3.3.3 C- DETERMINING THE INCIDENT CLEARANCE TIME (t_{CT}) AND D-DETERMINING THE EMERGENCY RESPONSE TIME($t_{(e)}$)

Step 1- Based on the input data defining the incident, the trees shown in Figures 3.3.4, 3.3.5, 3.3.6 and 3.3.7 are used to determine the initial mean value of the incident clearance time (t_{CT}). These trees are based on earlier research conducted by Kaan and Hobeika (1997) as discussed in section 2.3.3 on clearance times of incidents. The tree to be chosen is based on the incident type. Once the appropriate tree is chosen, the proper end-node is selected in this classification tree based on available information regarding police and emergency vehicles, number of vehicles involved, and whether a wrecker is used or not. The search is stopped at the end-node that represents the current information. The mean value in the end-node is adjusted according to the following conditions:

a) Weather conditions:

If Figure 3.3.1 indicates ice and snowy conditions, then the clearance time value is calculated as follows:

$$t_{CT} = \text{Mean Value} + \frac{\text{Upper Limit} - \text{Mean Value}}{0.5} \tag{3.3.1}$$

b) Night time:

If the incident occurred at night (indicated by dark in Figure 3.3.1), then:

$$t_{CT} = \text{Mean Value} + \frac{\text{Upper limit} - \text{Mean Value}}{0.2} \tag{3.3.2}$$

The adjustment factors were determined from the accident data and clearance times collected by Subramaniam (1993).

Step 2- The response time is added to the clearance time to determine the total time of constrained flow from the time of the occurrence of the incident. The response time is the time the emergency vehicle arrived on the scene. If this time is known from Figure 3.3.1, it is labeled $t_{(e)}$. Then the time the incident is cleared is $\left(t_{(e)} + t_{(CT)}\right)$.

If the arrival time of the emergency unit is not known, then 15 minutes are added to the start time of the incident ($t_{i(a)}$). If the incident occurred during the night, bad weather conditions, and involved spills, 20 minutes are added as the response time to $t_{i(a)}$.

Therefore, the time the incident is cleared is as follows:

a) $\left(t_{(e)} + t_{CT}\right)$ if $t_{(e)}$ is known

b) $\left(t_{i(a)} + 15\,\text{minutes} + t_{CT}\right)$ if traffic and weather conditions are normal, and $t_{(e)}$ is unknown

c) $\left(t_{i(a)} + 20\,\text{minutes} + t_{CT}\right)$ if traffic and weather conditions are not normal and $t_{(e)}$ is unknown.

Step 3- The initial clearance time is updated according to the new information obtained by the operator. Figure 3.3.2 outlines the additional information about the incident that corresponds with the status update cycle (possibly every 5 minutes) or when new information is received.

a) If the information remains the same, no change in t_{CT} is needed.

b) If the incident type is changed, determine a new t_{CT} similar to Step 1, but using a different tree path from Figures 3.3.3, 3.3.4, 3.3.5, and 3.3.6.

c) If incident type remains the same, but the current status compared to the initial condition is more severe (I) or less severe (II), then the following t_{CT} is adopted:

a. More severe condition:

$$t_{CT_{new}} = t_{CT_{old}} + \frac{\text{Upper limit} - \text{Mean Value}}{0.4} \qquad (3.3.3)$$

b. Less severe condition:

$$t_{CT_{new}} = t_{CT_{old}} - \frac{\text{Mean Value} - \text{Lower limit}}{0.2} \qquad (3.3.4)$$

The update status cycle is terminated after the incident is determined clear. The Figures 3.3.4 to 3.3.7 show classification trees used to determine clearance time. If the incident type is not known, a mean value of 25 minutes with a minimum of 20 minutes and maximum of 60 minutes is assumed to be the incident clearance time.

The three major types of incidents are ones which involve crashes, spills of hazardous materials and ones in which motorist requires assistance. The trees shown in Figures 3.3.4 to 3.3.7 can be used when the incident type is known.

If motorist assistance is required and the car or truck involved is disabled, Figure 3.3.7 should be used to determine the clearance time. If the incident is due to vehicle overheating, then depending on whether the vehicle is on fire or not, the mean clearance time varies from 13 min to 43 min.

If the incident involves a road hazard, like flat tire, zero fuel in vehicle, or debris on road, the mean clearance time for the incident is 12 min. If the incident involves a crash but there is no personal injury or fatality, it is classified as a property damage incident. For this case, Figure 3.3.5 will be used to determine the clearance time. If the incident is a crash, which involves a personal injury or fatality, Figure 3.3.6 should be used to determine the clearance time.

If the incident involves hazardous material spill, the time required to clear the incident depends on the type of the hazardous material. If it is a flammable material the mean clearance time is 180 min, if it is a toxic gas or nuclear material the mean clearance time is 300 min and if it is any other material the mean clearance time is 130 min.

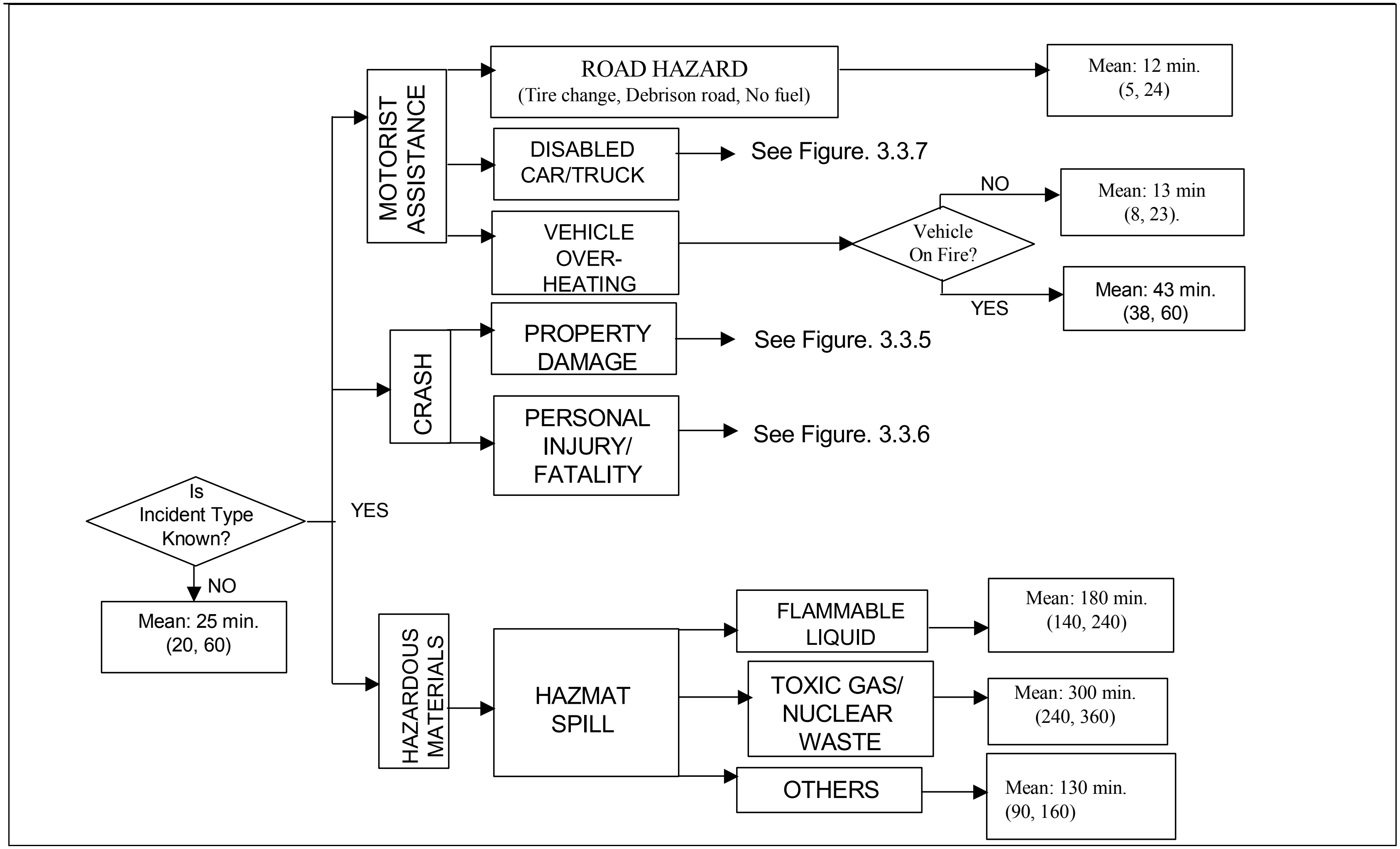


Figure 3.3.4: Decision Tree for Incident Clearance Time Prediction

(Adapted from Kaan and Hobeika (1997). Numbers in parenthesis are interval limits in minutes)

Figure 3.3.5 would be used if the crash is determined to be a property damage crash. The mean clearance time of an incident in which truck is involved will be 51 min. If a wrecker is used, the crash is very severe and the mean clearance time would be 68 min. If wrecker is not used, it would be 42 min.

If no truck is involved in the crash, the mean time is 41 min. If the number of vehicles involved in the incident is known, then depending on it, the estimated mean clearance time will vary. If 1 to 3 vehicles are involved, the time required would be 41 min and if more than 3 vehicles are involved, the mean clearance time would be 68 min. Again, depending on the number of police vehicles deployed and the number of wreckers deployed, the mean clearance time will vary. If the number of police vehicles used is high, the crash severity is high and thus the clearance time would increase with the number of police vehicles. Similar logic applies to the number of wreckers used.

In the case of a crash involving personal injury or fatality, the number of injured people affects the clearance time directly. If one or two people are involved, the time required to clear the incident would be 49 min, and if more than 2 persons are involved, the time required to clear the incident would be a mean of 71 min. Again, the number of police vehicles, ambulances and wreckers deployed will directly increase the mean incident clearance time as the severity of the incident is high when more of these emergency vehicles are used.

Example for calculating Incident clearance time:

Suppose an incident occurs on a freeway at $t_{i(a)}$ = 8:15 am under snowy conditions. The operator feeds the following information into the system.

1. Operator Info: Last Name: xyz, Reporting Agency = Police
2. Incident Details : Number of Cars involved = 1; Incident Type = Personal Injury Persons Injured = 2
3. Date/Time/Location : Incident Id = 1; Date: 09/21/2001, Reported start Time =8:15 am, Time incident is identified = 8:20 am, Time emergency units arrived on scene = Not Known, Freeway No. = I-81, Upstream interchange no. = 25, Downstream interchange no. =26 Location on link = Downstream
4. Personnel: Police Vehicles = 1, Fire Units =0, Ambulance = 1, Wrecker =1
5. Lane Info: No. of Lanes on link = 3; Blocked lanes =2
6. Weather: Conditions: Icy, Light: Bright, Temperature < 32
7. Other Info: None

Using chart 3.3.6, the clearance time for the incident would vary between 31 and 45 min the average would be 35 min. Since the conditions are snowy, the clearance time would be incremented as follows:

$$t_{CT} = \text{Mean Value} + \frac{\text{Upper Limit} - \text{Mean Value}}{0.5} = 35 + (45\text{-}35)/0.5 = 55 \text{ min}$$

As the time the emergency response units reach the scene of the incident is not known, the time the incident would be cleared would be estimated to be $t_{i(a)}$ + 20 min + 55 min = 9:30 am. Travel times are calculated for the present time using this estimate.

When the update information is obtained about the incident after 15 minutes the operator inputs the following information in Figure 3.3.2.

1. Incident Id = 1; Current Time = 8:35 am
2. Blocked Lanes = 1
3. Time Blocked lanes removed = Not Known
4. Blocked Shoulders: None
5. Time incident is declared clear = Not Known
6. Change in Incident type = No
7. Conditions compared to initial status = Less severe

The condition now being less severe, the time required to clear the incident would now be:

$$t_{CT_{new}} = t_{CT_{old}} - \frac{\text{Mean Value} - \text{Lower limit}}{0.2} = 55 – (35\text{-}31)/0.2 = 35 \text{ minutes}$$

Hence the estimated incident clearance time is now 9:10 am.

The final update on the incident is as follows:

1. Incident Id = 1; Current Time = 9:15 am
2. Blocked Lanes = 0; Time blocked lane is cleared = 9:10am
3. Blocked Shoulders: None

4 Time incident is declared clear = 9:10 am

5 Change in Incident type = No

6 Conditions compared to initial status = Same

The incident is thus cleared at 9:10 am and traffic resumes normal flow on the link. As long as the incident lasts, the bottleneck algorithm described in Case A will be used to estimate travel times. Once the incident is cleared and normal flow conditions resume, the algorithm of Case C, i.e no-incident, no-closure case algorithm will be used.

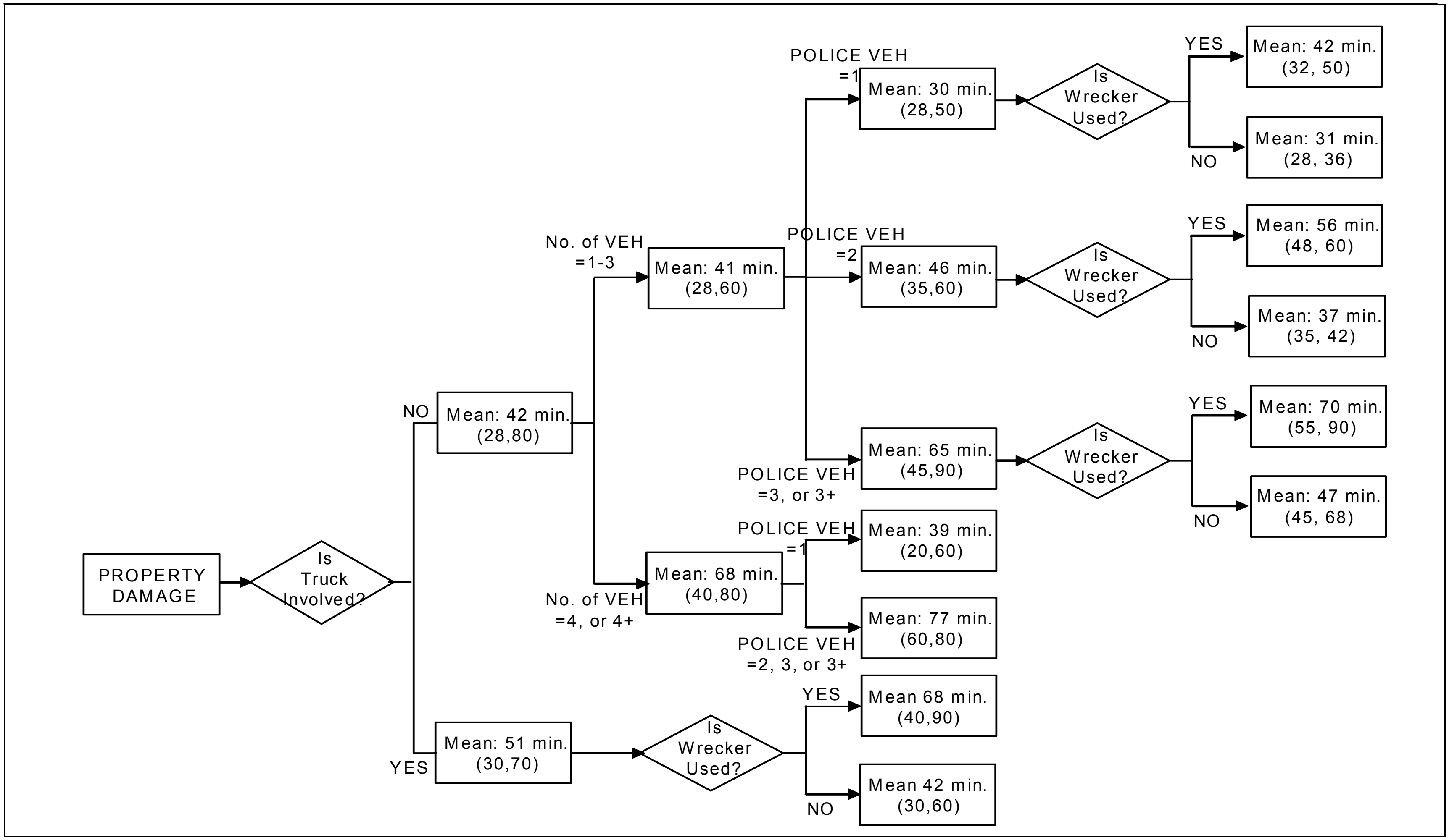
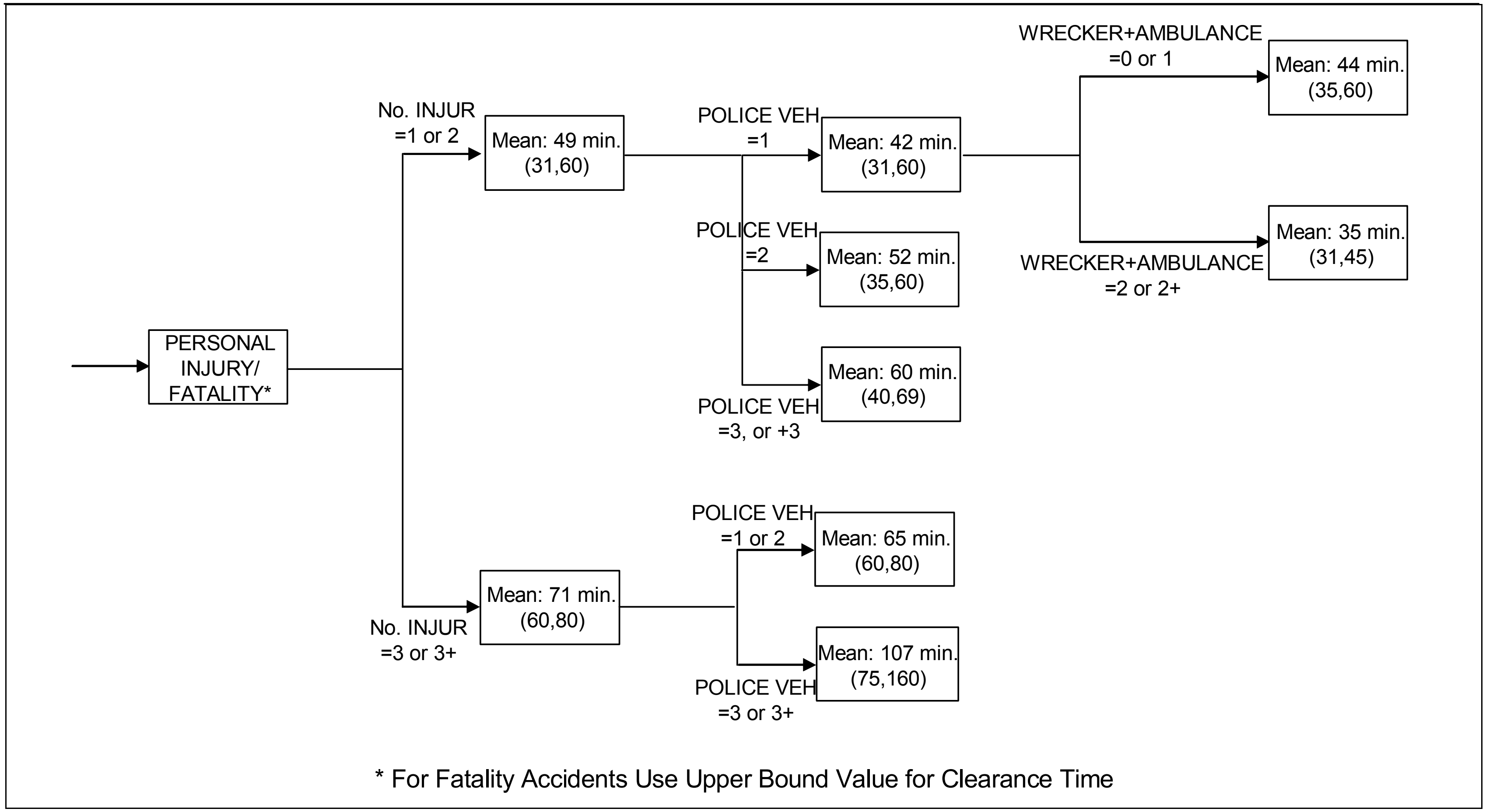


Figure 3.3.5: Decision Tree for Incident Clearance Time Prediction of Property Damage Incidents (Adapted from Kaan and Hobeika (1997). Numbers in parenthesis are interval limits in minutes)



* For Fatality Accidents Use Upper Bound Value for Clearance Time

Figure 3.3.6: Decision Tree for Incident Clearance Time Prediction Injury Incident

(Adapted from Kaan and Hobeika (1997). Numbers in parenthesis are interval limits in minutes)

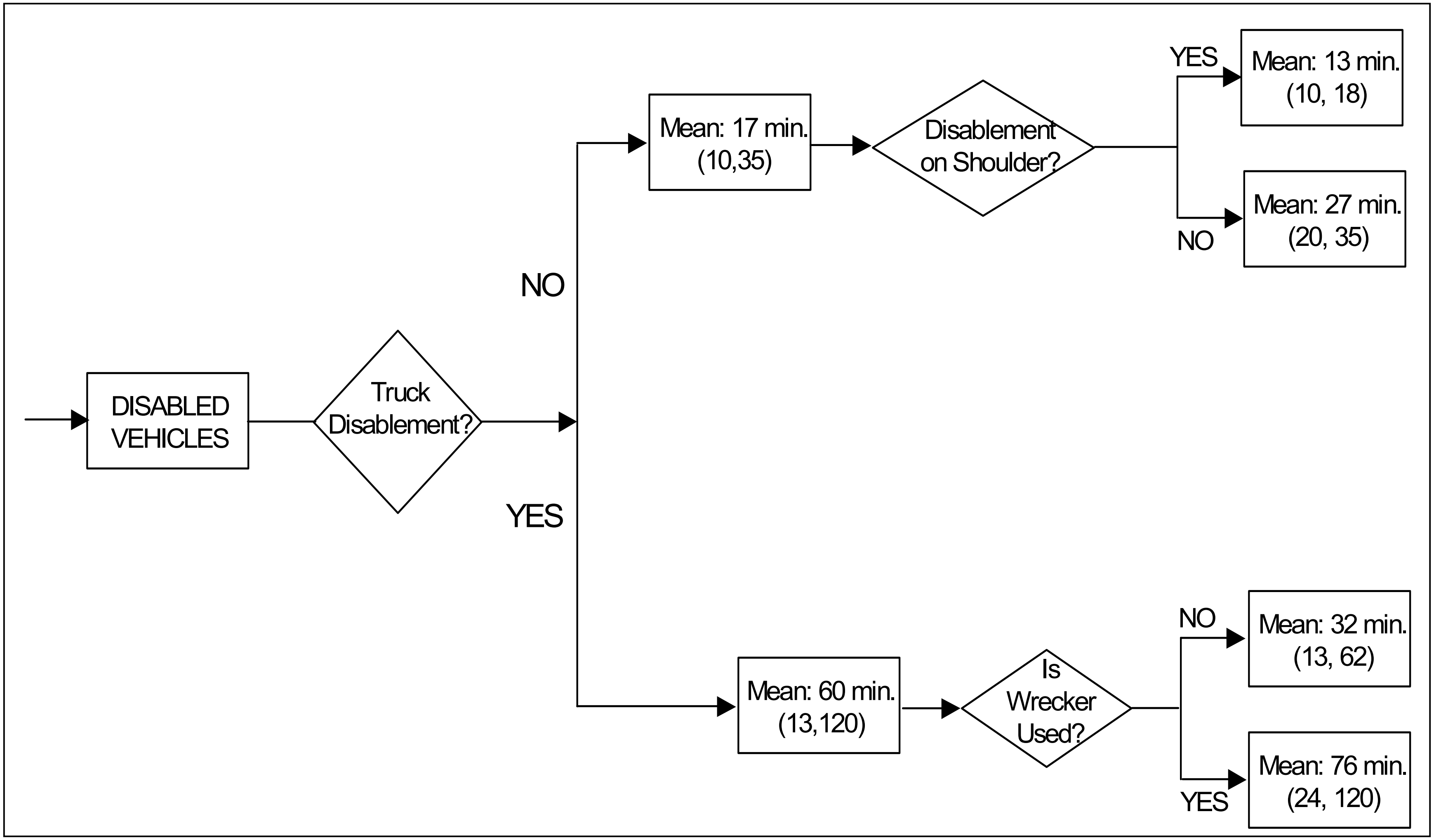


Figure 3.3.7: Decision Tree for Incident Clearance Time Prediction. Disabled Car or Truck (Adapted from Kaan and Hobeika (1997). Numbers in parenthesis are interval limits in minutes)

3.3.4 E AND F- TRAVEL TIME ESTIMATIONS ON THE AFFECTED UPSTREAM LINKS

Travel time estimation is conducted for each time interval between $t_{i(a)}$ (the start time of the incident and $t_{(e)} + t_{CT}$ (the time the incident is cleared). This algorithm is also continued after the incident is cleared till the traffic reaches normal flow. The travel time estimation procedure is similar to the Case A algorithm for lane closure. Here the lane closure is caused by an incident, and is reopened for traffic when the incident is cleared. The time of clearance of the incident determines the recovery period to normal traffic flow. The location of the incident, as well as the number of lanes available for traffic are obtained from the incident input data provided in Figure (3.3.1). Three possible locations of the incident are provided in the Figure. For travel time estimation algorithm, these locations are converted as follows:

a) Upstream- The incident is located at $\frac{1}{3}$ length of the link from upstream node

b) Midstream- The incident is located at $\frac{1}{2}$ length of the link from upstream node

c) Downstream- The incident is located at $\frac{2}{3}$ length of the link from upstream node

The bottleneck algorithm described in Case A will be used directly for travel time calculations as long as the incident causes the lanes to be closed. Once the lanes are opened, the number of lanes at the bottleneck increases to a new a value of N'_{i_b} thus leading to an increase in capacity of the bottleneck. If the upstream flow is greater than this new capacity the shockwave will continue moving backward, but now with a slower velocity of

$$W_u = \frac{(\overline{q}_{i_u} \times N_{i_u} - C \times N'_{i_b})/N_{i_u}}{\overline{K}_{i_u} - \overline{K}_{i_b}} \text{ mph} \qquad (3.3.5)$$

In case the upstream arriving flow is less than the new downstream capacity, the shockwave will start to move forward along the direction of traffic at a rate of

$$W_d = \frac{\left(C \times N'_{i_b} - \bar{q}_{i_u} \times N_{i_u}\right) / N_{i_u}}{\bar{K}_{i_b} - \bar{K}_{i_u}} \text{ mph} \tag{3.3.6}$$

The travel time calculation procedure remains the same as in Case A, but, with the new velocities shown above. Examples for this case are provided in Section 3.2.1.

3.4 CASE C TRAVEL TIME ESTIMATION UNDER NO-INCIDENT NO CLOSURE CASE

As discussed in Chapter 2, the travel time $t_i(k)$ on a road section ‘i’ during time interval k can be estimated with good accuracy using the relationship

$$t_i(k) = \frac{1}{2} \times \left[\frac{L_i}{v_{A,k}} + \frac{L_i}{v_{B,k}} \right] \qquad (3.4.1)$$

where $v_{A,k}$ and $v_{B,k}$ are the time-mean speeds at section ends A and B, respectively, during time interval k, and L_i is the section length. (Lindveld et al (1999)) This assumption behind this estimate is that traffic conditions (speed, flow and density) remain stationary during the time period k and are homogenous across the section. The accuracy of this method depends on length of period k and length of section L_i.

A similar procedure is adopted in this research to calculate travel times under no-incident no-closure case. Instead of the time-mean speeds $v_{A,k}$ and $v_{B,k}$ at the upstream and downstream ends, the ratios of flow to density at the detector locations are used.

The travel time TT_i on a link ‘i’ is, thus, estimated to be

$$TT_i = \frac{1}{2} \times \left[\frac{L_i \times \overline{K}_{i_u}}{\overline{q}_{i_u}} + \frac{L_i \times \overline{K}_{i_d}}{\overline{q}_{i_d}} \right] \qquad (3.4.2)$$

where, L_i is the length of the freeway segment, $\overline{q}_{i_u}$ and $\overline{q}_{i_d}$ are point estimates of flows at the upstream and downstream detector locations, and $\overline{K}_{i_u}$ and $\overline{K}_{i_d}$ are point estimates of the densities at the upstream and downstream detector locations respectively. This equation is used for travel time estimation as long as the densities at the detector locations remain less than 60 vpmpl. In case the density at downstream detector exceeds 60 vpmpl while the upstream detector shows densities less than 60 vpmpl, a compression wave might exist which would result in higher travel time on the link. Then, TT_i in equation (3.4.2) is augmented by 20%.

$$TT_i = \frac{1.2}{2} \times \left[\frac{L_i \times \overline{K}_{i_u}}{\overline{q}_{i_u}} + \frac{L_i \times \overline{K}_{i_d}}{\overline{q}_{i_d}} \right] \qquad (3.4.3)$$

In case the density at both the upstream and downstream detectors exceeds 60 vpmpl, the travel time TT_i in equation (3.4.2) is augmented by 40%.

$$TT_i = \frac{1.4}{2} \times \left[\frac{L_i \times \overline{K}_{i_u}}{\overline{q}_{i_u}} + \frac{L_i \times \overline{K}_{i_d}}{\overline{q}_{i_d}} \right] \tag{3.4.3}$$

The values 1.2 and 1.4 are obtained and approximated from the traditional speed and density relationship.

Example for Case C Algorithm:

Consider a freeway segment 3 miles long with detectors at the upstream and downstream ends. The readings of the detectors at five minute interval are as shown below:

Time	$\overline{q}_{i_u}$	$\overline{K}_{i_u}$	$\overline{q}_{i_d}$	$\overline{K}_{i_d}$
10:45	2008	26.55	2020	26.48
10:50	1996	25.81	2020	27.32
10:55	2000	25.96	1976	26.03
11:00	2000	26.15	1972	25.76
11:05	2004	26.54	2012	26.97
11:10	2004	26.17	2044	26.66
11:15	2016	26.29	1976	25.86
11:20	1988	25.95	2008	26.16
11:25	2008	26.49	2004	26.88
11:30	2008	26.39	2008	26.59
11:35	2004	26.32	2012	26.52
11:40	2000	26.44	1988	26.29
11:45	2008	26.55	2020	26.48

Table 3.4.1:Case C Example Flows and Densities

The travel time for the time period ending 10:45 is calculated as shown below

$$TT_i = \frac{1}{2} \times \left[\frac{L_i \times \overline{K}_{i_u}}{\overline{q}_{i_u}} + \frac{L_i \times \overline{K}_{i_d}}{\overline{q}_{i_d}} \right] = 60 \times \frac{1}{2} \times \left[\frac{3.0 \times 26.55}{2008} + \frac{3.0 \times 26.48}{2020} \right] = 2.37 \text{ min}$$

The travel time for the remaining periods is calculated similarly. A summary of the results of travel time estimations for this example is provided below.

Time	Travel Time (min)
10:45	2.37
10:50	2.381
10:55	2.354
11:00	2.352
11:05	2.398
11:10	2.349
11:15	2.351
11:20	2.347
11:25	2.394
11:30	2.375
11:35	2.369
11:40	2.38

Table 3.4.2: Case C Example Travel Times

3.5 CONCLUSIONS

This chapter presented the proposed system for travel time estimation on urban freeways. Algorithms for travel time estimation under all traffic conditions are presented. Examples for the implementation of the algorithms are also shown. The next chapter provides procedure for validation of the proposed system.

CHAPTER 4 COMPARISON WITH CORSIM

4.1 INTRODUCTION

The proposed system for travel time estimation is now compared with simulation software. CORSIM 5.0 was used to perform this comparison. The system is compared in all three cases i.e when there are no incidents or lane closures, when there are lane closures, and, when there are incidents on freeways.

CORSIM (CORridor SIMulation) is a micro-simulation software developed by FHWA for simulation of networks of freeway and surface streets. CORSIM consists of two packages known as NETSIM (NETwork SIMulation) and FRESIM (FREeway SIMulation), which simulate traffic at microscopic level. NETSIM is used to simulate urban surface street conditions while FRESIM is used to simulate freeway conditions. CORSIM simulates traffic and traffic control systems using commonly accepted vehicle and driver behavior models. The freeway simulation component, FRESIM is used for the purpose of comparing the algorithms of Case A, Case B and Case C.

The methodology adopted in all three cases is similar. First, the freeway to be simulated is coded in CORSIM and detectors are placed on it at suitable locations. Traffic of different volumes is allowed on to the freeway and detector output is extracted. This detector output is used as an input to the algorithms in Case A, Case B and Case C. Then, travel times for individual vehicles are obtained from CORSIM output file. In order to obtain travel times for individual vehicles in CORSIM, the .TSD output file that gives the snapshot data at every time step, is opened and interpreted. The file is printed in binary format by CORSIM. It contains information related to the simulation at each time step. A part of this information is vehicle information. At each second, the following information about each vehicle is written to the .TSD output file.

(Source: TRAFVU File Description Document, 2001, http://www.fhwa-tsis.com/documents.htm)

1. Global Vehicle ID : global vehicle ID of first vehicle in this message
2. Fleet: 0 = Auto, 1 = truck, 2 = carpool, 3 = bus
3. Vehicle Type: CORSIM vehicle type
4. Vehicle Length: vehicle length in feet

5. Driver Type: CORSIM driver type
6. Lane ID: CORSIM ID of lane in which vehicle is traveling
7. Vehicle Position: vehicle’s distance from up-stream node of link in feet
8. Previous USN: up-stream node ID of the previous link the vehicle traveled
9. Turn Code: vehicle turn code: 0 = left, 1 = through, 2 = right, 3 = left diagonal, 4 = right diagonal, 5 = source emission
10. Queue Status: 0=vehicle is currently not in queue, 1 = vehicle is currently in queue
11. Acceleration: vehicle’s instantaneous acceleration in feet/second/second
12. Velocity: vehicle’s instantaneous velocity in feet/second
13. Lane Change Status: 0 = vehicle does not want to change lanes, 1 = vehicle wants to change lanes
14. Target Lane: CORSIM ID of lane vehicle would like to occupy
15. Destination Node: node ID of the vehicles destination node
16. Leader Vehicle ID: global ID of vehicle’s leader vehicle
17. Follower Vehicle ID: global ID of vehicle’s follower vehicle
18. Previous Lane ID: lane ID of lane the lane that the vehicle was previously in

The .TSD file is read using a C++ program (Bin_to_ascii.cpp) to extract the vehicle information. Since, the .TSD file is in binary format, the vehicle information is written to a text file in ASCII format. This ASCII file is then sorted by Vehicle Id to segregate vehicles. Vehicle travel times are then extracted from this sorted file by means of one more C++ program (ttcorsim.cpp). This program scans through the vehicle messages to find out change in vehicle ID. Once a new vehicle ID is detected, the difference in time of the first message and last message for the previous vehicle is calculated. This time is the travel time for the vehicle. The travel times obtained will be for both vehicles that completed their trips and for vehicles that did not complete their trips. In order to make a better comparison, only vehicles that completed the trips from the beginning to the end of the freeway segment are considered. Another C++ program is used to average the travel times for every five-minute interval. The travel times of individual vehicles are then compared against the travel times calculated by the algorithms. Plots of the calculated travel times (from algorithms) versus ‘actual’ travel times (average travel times of individual vehicles) are drawn.

4.2 COMPARISON OF CASE A ALGORTIHM FOR TRAVEL TIME ESTIMATION UNDER BOTTLENECK CONDITIONS WITH CORSIM

A six-mile long freeway section with a lane closed for road-work is considered in this case. The road-work spans 820 ft and starts 2.84 miles from the upstream end. The length of the freeway downstream of the bottleneck is 3.0 miles.

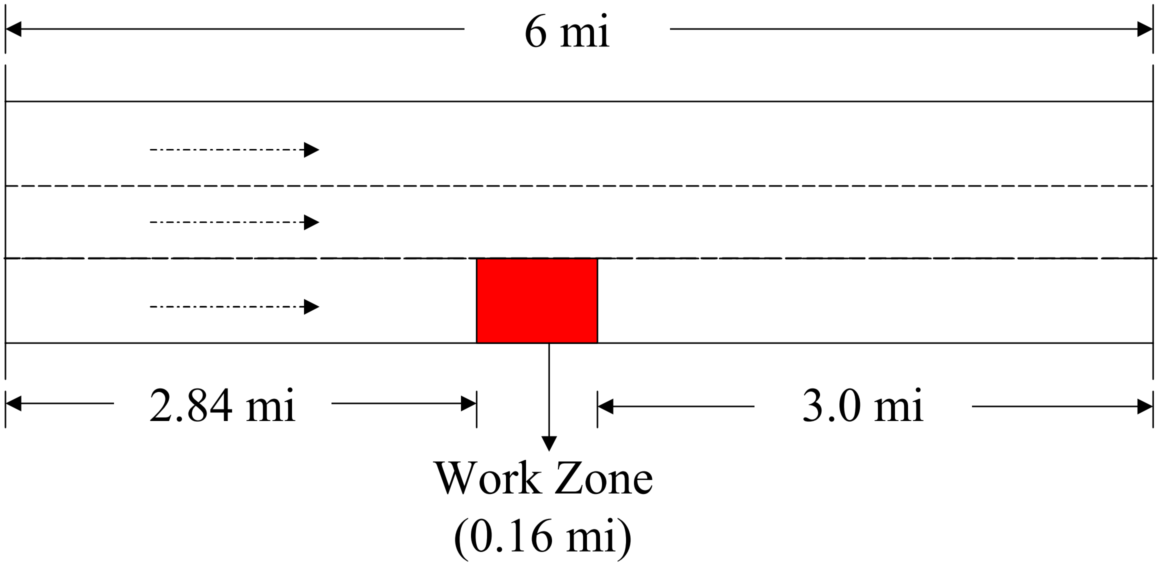


Figure 4.1: Bottleneck on a Freeway

This freeway segment is simulated in CORSIM. Detectors are placed at various locations on this section of freeway. The flows and densities given by detectors located at the upstream and downstream ends of the freeway are used in the bottleneck algorithm discussed in Case A of Chapter 3 to calculate travel times. The procedure used is similar to the example discussed in Case A.

CORSIM INPUT: Record types used and description

The code used for simulating the freeway in CORSIM is provided in APPENDIX A. A discussion on important entries in the code is provided.

1. Record Type 01: Run Identification: Name of person coding the network and date are entered using this record.
2. Record Type 02: Run Control: FRESIM Point Processing is desired and hence entry 2 is set to 1. This is necessary in order to obtain detector output in the .OUT file. The maximum initialization time is set to 15 minutes.

3. Record Type 03: Time period Specification: The simulation is performed for 120 minutes, hence, entry 1 is coded as 7200 seconds.
4. Record Type 04: Time intervals and Time Steps per Time Period: Entry 2 is coded as 60 seconds, which is the default value.
5. Record Type 05: Reports: Time to begin the first set of reports is 0 and duration of first reporting period is 7200 seconds. The time between each intermediate set of reports is 300 seconds (5 minutes).
6. Record Type 19: Freeway Link Geometry: 3 lanes are used throughout the freeway segment.
7. Record Type 20: Freeway Link Operation: A free flow speed of 65 mph is specified.
8. Record Type 25: Freeway Turn Movements: All vehicles are coded as through vehicles
9. Record Type 28: Surveillance Specification: This record allows the simulation of surveillance system. Using this record, detectors were placed at the beginning and end of the freeway segment. The detector type used was coupled pair of short loops with 6 ft spacing.
10. Record Type 29: Incident Specification: This record is used for simulating incidents. In order to simulate lane closures, an incident can be coded in place of the lane closures and a suitable rubbernecking factor can be specified. A rubbernecking factor of 0% was used in this research to simulate work zone conditions.
11. Record Type 53: Time Varying Entry Link Volumes: If this record is coded, the values in Record type 50 are overwritten with values in this record. The volume entering at node 1 of the network is coded in this record. The inflow is specified to be at the rate of 5000 vph for the first 45 minutes and 2800 vph after that till the end of the simulation.
12. Record Type 64: Point Processing Specification: Output is requested at 5 minute intervals from the detectors by the use of this record. Average vehicle length is assumed to be 17 feet.

13. Record Type 67: Point Processing Station Numbers: The stations from which point processing output is desired is specified using this record.

A summary of the calculations is provided in Table 1. It should be noted that the capacity at the bottleneck is assumed to be 1950 vphpl in this case. Travel times of individual vehicles are calculated using the snapshot data from .TSD file of CORSIM. The travel times thus obtained are averaged for every five-minute interval. These travel times are also shown in Table 1 under the column "CORSIM".

The Mean Absolute Error and the Mean Squared Error are calculated as:

$$MAE = \frac{\sum_{i=1}^{n} Observed - Estimated}{n}$$

$$MSE = \frac{\sum_{i=1}^{n} (Observed - Estimated)^2}{n}$$

A plot showing the comparison of travel times obtained from the algorithm of Case A, and, actual travel times of vehicles, is shown in Figure 4.2. The Mean Absolute error in travel time estimates was calculated to be 2.819 minutes min and the Mean Squared error is found to be 8.844 min^2. These results indicate that the algorithm works quite accurately, considering the fact that no other algorithm is able to give even approximate estimates of travel times under bottleneck conditions at a macroscopic level.

Travel Time Estimation under Lane closure

lu	2.84	ld	3.16
N iu	3	Nib	2

Time	n	t	q u	k u	C	k b	q d	k d
7:30	1	5	1660	20.7	1950	120	1528	19.6
7:35	2	10	1672	20.9	1950	120	1288	16.2
7:40	3	15	1664	20.8	1950	120	1264	16
7:45	4	20	1668	20.9	1950	120	1264	16
7:50	5	25	1660	20.8	1950	120	1248	15.6
7:55	6	30	1676	21	1950	120	1212	15.3
8:00	7	35	1668	20.9	1950	120	1216	15.3
8:05	8	40	1672	21.1	1950	120	1228	15.4
8:10	9	45	1664	20.8	1950	120	1208	15.2
8:15	10	50	968	11.7	1950	120	1272	16.1
8:20	11	55	940	11.6	1950	120	1216	15.4
8:25	12	60	928	11.3	1950	120	1264	15.8
8:30	13	65	940	11.5	1950	120	1316	16.5
8:35	14	70	928	11.4	1950	120	1232	15.6
8:40	15	75	932	11.4	1950	120	1288	16.2
8:45	16	80	940	11.6	1950	120	1268	16
8:50	17	85	932	11.4	1950	120	1328	16.6
8:55	18	90	936	11.5	1950	120	1280	16.2

w	QR	Qn	Qm	ttbn	QL	Tti	Tti (min)	CORSIM	AE	SE
-3.63	1305	108.8	108.8	0.028	0.302	0.1	6.007	6.93	0.923	0.852
-3.75	1352	112.6	221.4	0.057	0.615	0.124	7.466	8.479	1.014	1.027
-3.67	1321	110.1	331.5	0.085	0.921	0.149	8.939	10.13	1.191	1.419
-3.71	1337	111.4	442.9	0.114	1.23	0.174	10.42	11.74	1.315	1.73
-3.63	1307	108.9	551.8	0.141	1.533	0.197	11.84	13.64	1.801	3.242
-3.8	1368	114	665.7	0.171	1.849	0.223	13.38	15.43	2.044	4.176
-3.71	1337	111.4	777.1	0.199	2.159	0.248	14.86	17.18	2.326	5.411
-3.76	1354	112.8	889.9	0.228	2.472	0.273	16.35	18.88	2.524	6.371
-3.67	1320	110	1000	0.256	2.778	0.297	17.82	20.53	2.705	7.316
3.066	-1104	-91.98	908	0.233	2.522	0.277	16.6	20.18	3.585	12.85
3.321	-1196	-99.63	808.3	0.207	2.245	0.255	15.28	19.1	3.827	14.65
3.423	-1232	-102.7	705.7	0.181	1.96	0.231	13.86	17.83	3.968	15.75
3.319	-1195	-99.57	606.1	0.155	1.684	0.209	12.55	16.44	3.892	15.15
3.425	-1233	-102.8	503.3	0.129	1.398	0.187	11.21	15.24	4.027	16.22
3.388	-1220	-101.7	401.7	0.103	1.116	0.164	9.822	13.95	4.123	17
3.321	-1196	-99.63	302.1	0.077	0.839	0.142	8.519	12.38	3.861	14.91
3.389	-1220	-101.7	200.4	0.051	0.557	0.119	7.128	10.63	3.504	12.28
3.353	-1207	-100.6	99.78	0.026	0.277	0.097	5.818	9.921	4.103	16.83

Table 4.1: Travel time Estimation Under Bottleneck Conditions

w -> Shockwave Speed QR -> Queuing or Dissipation rate

Qn -> Number of vehicles added or removed from queue in time interval tn

Q_m -> The total number of vehicles that are in queue.

ttbn-> Average Travel time in queue

QL -> Queue Length in miles

TTi -> Average Travel Time on link i in hours. (Including upstream and downstream sections)

TTi (mins)-> Average Travel Time on link i in minutes. (Including upstream and downstream sections)

CORSIM -> Average Travel Times on link i calculated from individual vehicle travel times in CORSIM

AE -> Absolute Error in Estimation; SE-> Squared Error

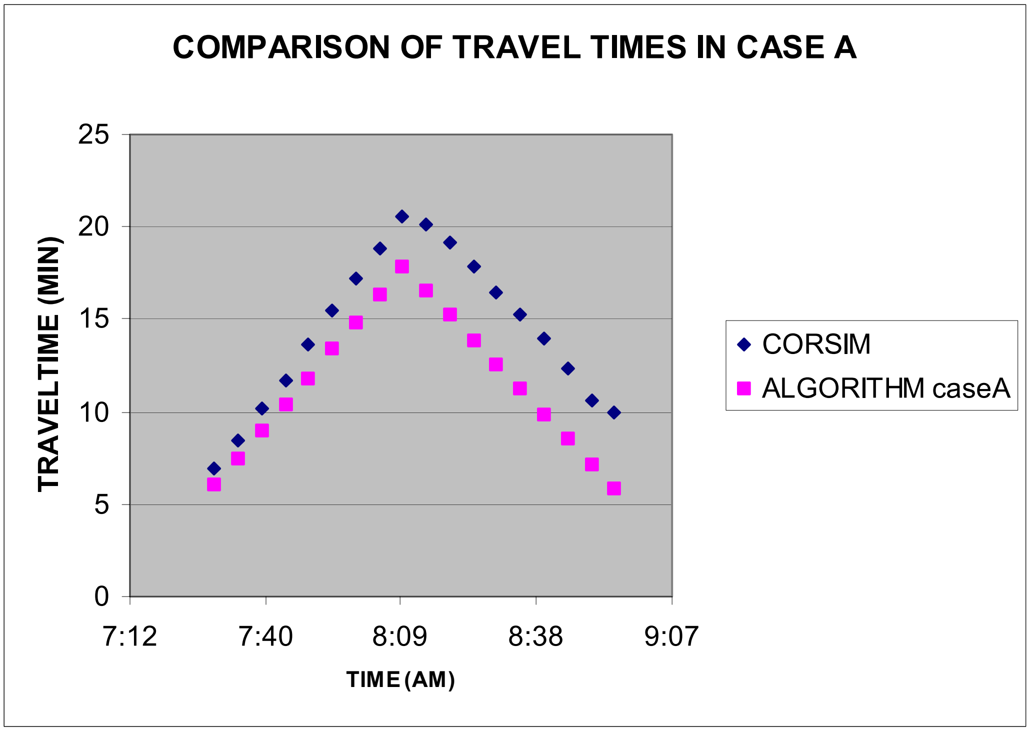


Figure 4.2: Comparison of Travel times in Case A

4.3 COMPARISON OF CASE B ALGORITHM FOR TRAVEL TIME ESTIMATION UNDER INCIDENT CONDITIONS WITH CORSIM

A six-mile long freeway section similar to the one used in Case A is considered. An incident occurs on the freeway blocking the right lane as shown in the figure. The extent of the lane closure is 820 ft and it starts 2.84 miles from the upstream end. The length of the freeway segment downstream of the incident is 3.0 miles.

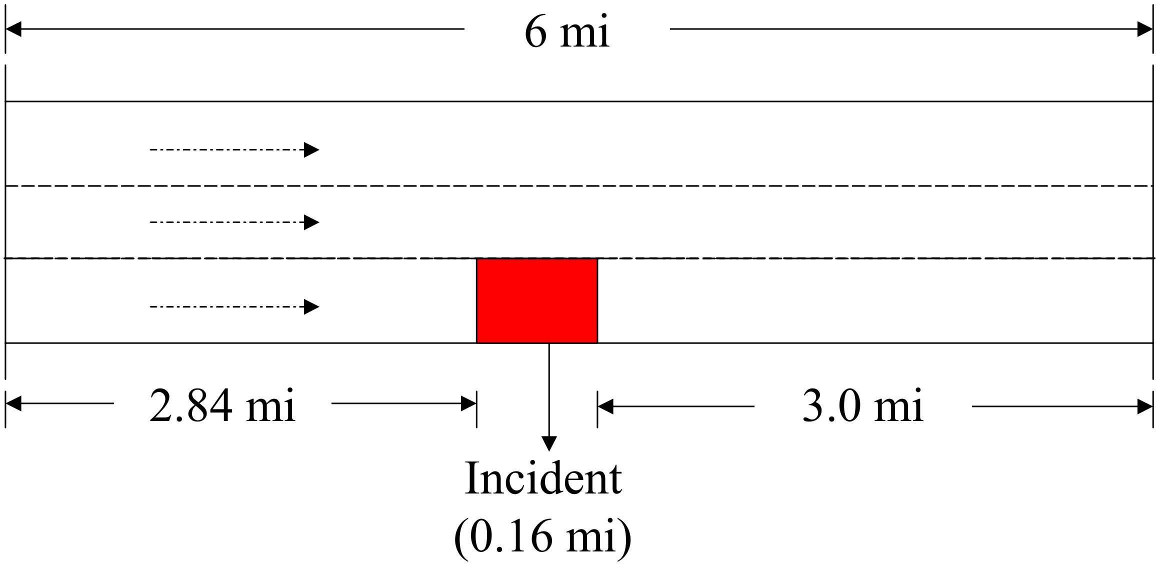


Figure 4.3: Incident on a Freeway

This freeway segment is shown in Figure 4.3. The incident in simulated in CORSIM. The incident is assumed to be cleared 45 min after it occurs, thus opening all three lanes for traffic. It is assumed that the time of clearance of the incident is obtained from the trees shown in Figures 3.3.4-7. A flow of 5000 vph is allowed onto the freeway segment during the first 45 minutes and then the flow is reduced to 2800 vph. This reduction in flow may be caused due to vehicles diverting to other routes after receiving information about the incident on this segment. Detectors are placed at various locations on this section of freeway. The flows and densities given by detectors located at the upstream and downstream ends of the freeway are used in the incident algorithm discussed in Case B of Chapter 3 to calculate travel times. The procedure used is similar to the example discussed in Case A. A summary of the calculations is provided in Table 4.2. It should be noted that the capacity at the incident is assumed to be 1950 vphpl in this case. Travel times of individual vehicles are calculated using the snapshot data from

.TSD file of CORSIM. The travel times thus obtained are averaged for every five-minute interval. These travel times are also shown in Table 1 under the column "CORSIM".

A comparative plot showing the travel times obtained by the algorithm of Case A versus actual travel times of vehicles is shown in Figure 4.4.

CORSIM INPUT: Record types used and description

The code used for simulating the freeway in CORSIM is provided in APPENDIX A. A discussion on important entries in the code is provided.

1. Record Type 01: Run Identification: Name of person coding the network and date are entered using this record.
2. Record Type 02: Run Control: FRESIM Point Processing is desired and hence entry 2 is set to 1. This is necessary in order to obtain detector output in the .OUT file. The maximum initialization time is set to 15 minutes.
3. Record Type 03: Time period Specification: The simulation is performed for 120 minutes, hence, entry 1 is coded as 7200 seconds.
4. Record Type 04: Time intervals and Time Steps per Time Period: Entry 2 is coded as 60 seconds, which is the default value.
5. Record Type 05: Reports: Time to begin the first set of reports is 0 and duration of first reporting period is 7200 seconds. The time between each intermediate set of reports is 300 seconds (5 minutes).
6. Record Type 19: Freeway Link Geometry: 3 lanes are used throughout the freeway segment.
7. Record Type 20: Freeway Link Operation: A free flow speed of 65 mph is specified.
8. Record Type 25: Freeway Turn Movements: All vehicles are coded as through vehicles
9. Record Type 28: Surveillance Specification: This record allows the simulation of surveillance system. Using this record, detectors were placed at the beginning and end of the freeway segment. The detector type used was coupled pair of short loops with 6 ft spacing.

10. Record Type 29: Incident Specification: This record is used for simulating incidents. The duration of the incident is specified as 45 min. The warning sign for the incident is specified to be located 60 ft ahead of the incident.
11. Record Type 53: Time Varying Entry Link Volumes: If this record is coded, the values in Record type 50 are overwritten with values in this record. The volume entering at node 1 of the network is coded in this record. The inflow is specified to be at the rate of 5000 vph for the first 45 minutes and 2800 vph after that till the end of the simulation.
12. Record Type 64: Point Processing Specification: Output is requested at 5 minute intervals from the detectors by the use of this record. Average vehicle length is assumed to be 17 feet.
13. Record Type 67: Point Processing Station Numbers: The stations from which point processing output is desired is specified using this record.

Travel Time Estimation under Incident conditions

lu	2.84	ld	3.16	l(i-1)	6
N iu	3	Nib	2		

Time	n	t	q u	k u	C	k b	q d	k d
7:30	0	0	1664	21.2	1950	120	1584	20.29
7:35	1	5	1668	21.1	1950	120	1400	17.85
7:40	2	10	1672	20.94	1950	120	1348	16.9
7:45	3	15	1664	20.76	1950	120	1204	14.95
7:50	4	20	1660	20.73	1950	120	1248	15.65
7:55	5	25	1668	21.15	1950	120	1228	15.32
8:00	6	30	1676	21.31	1950	120	1216	15.15
8:05	7	35	1668	20.9	1950	120	1300	16.31
8:10	8	40	1656	20.93	1950	120	1212	15.35
8:15	9	45	980	12.09	1950	120	1376	17.28
8:20	10	50	928	11.29	1950	120	2092	27.11
8:25	11	55	936	11.55	1950	120	2248	29.02

w	QR	Q		tt	L		n	o	E	SE
-3.684	1326	110.5	110.5	0.028	0.307	0.101	6.065	6.916	0.851	0.725
-3.721	1340	111.6	222.2	0.057	0.617	0.125	7.523	8.716	1.193	1.424
-3.755	1352	112.7	334.8	0.086	0.93	0.149	8.963	10.8	1.836	3.369
-3.668	1320	110	444.8	0.114	1.236	0.173	10.4	12.26	1.861	3.465
-3.627	1306	108.8	553.6	0.142	1.538	0.198	11.87	13.62	1.75	3.064
-3.723	1340	111.7	665.3	0.171	1.848	0.223	13.36	14.37	1.014	1.029
-3.81	1372	114.3	779.6	0.2	2.166	0.248	14.87	15.17	0.294	0.087
-3.714	1337	111.4	891	0.228	2.475	0.273	16.36	15.26	-1.103	1.216
-3.594	1294	107.8	998.8	0.256	2.775	0.297	17.82	14.49	-3.325	11.06
8.989	-3236	-269.7	729.2	0.187	2.025	0.237	14.2	12.49	-1.715	2.942
9.401	-3384	-282	447.1	0.115	1.242	0.175	10.5	9.738	-0.764	0.584
9.35	-3366	-280.5	166.7	0.043	0.463	0.113	6.77	6.944	0.173	0.03

Table 4.2: Travel Time Estimation Under Incident Conditions

w -> Shockwave Speed; QR -> Queuing or Dissipation rate

Qn -> Number of vehicles added or removed from queue in time interval tn

Q_m -> The total number of vehicles that are in queue.

ttbn-> Average Travel time in queue

QL -> Queue Length in miles

TTi -> Average Travel Time on link i in hours. (Including upstream and downstream sections)

TTi (mins)-> Average Travel Time on link i in minutes. (Including upstream and downstream sections)

CORSIM -> Average Travel Times on link i calculated from individual vehicle travel times in CORSIM

AE -> Absolute Error in Estimation SE-> Squared Error

The Mean Absolute Error in travel time estimates was calculated to be 0.37 minutes and Mean Square error is found to be 2.416 minutes^2.

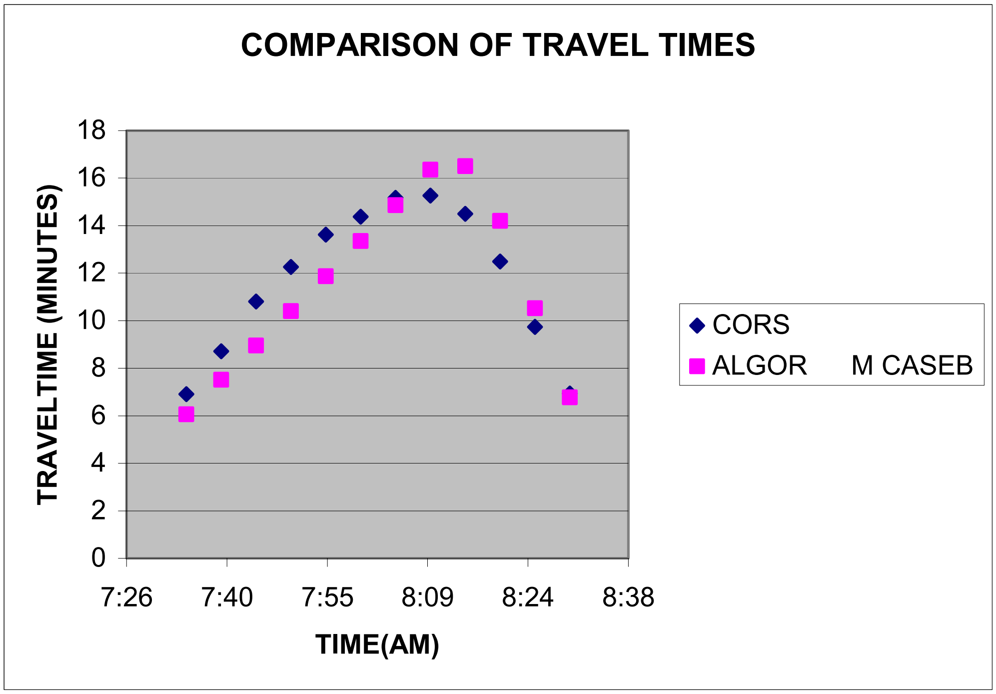


Figure 4.4: Comparison of Travel Times Under Incident Conditions

4.4 COMPARISON OF CASE C ALGORITHM FOR NO-INCIDENT NO-CLOSURE CASE WITH CORSIM

A freeway link of length 6 miles as shown in Figure 4.5, is considered to verify the no-incident no-closure case algorithm. Detectors are located at the upstream and downstream ends of the link as shown in the figure. The flows at the upstream detector DT_{iu} are denoted by q_{iu}, k_{iu} and the flows and densities at the downstream detector are denoted by q_{id}, k_{id}.

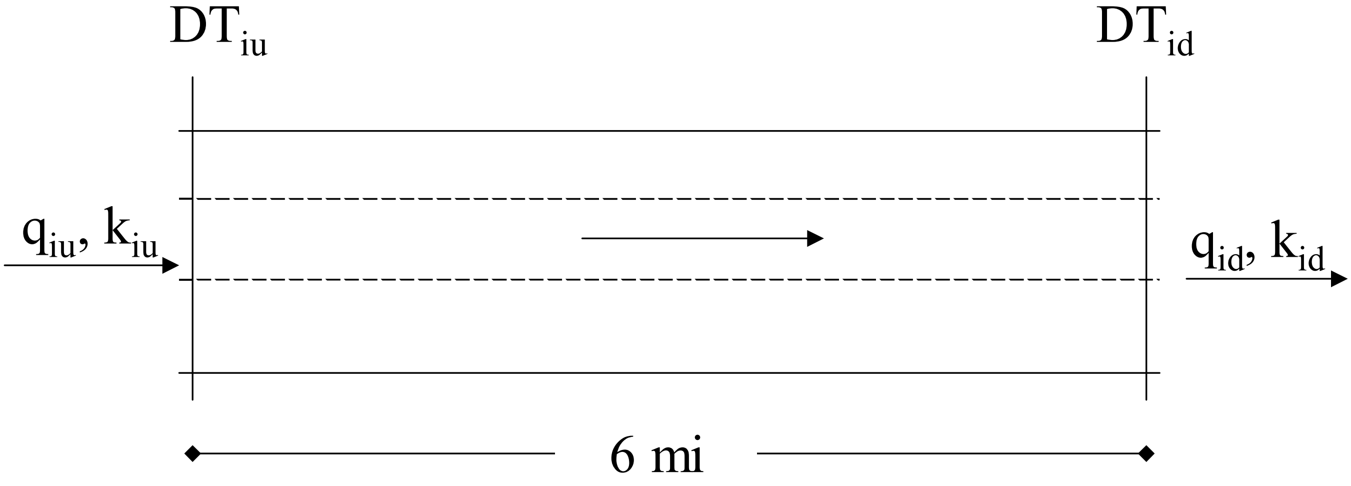


Figure4.5: Link with No-incident No-closure

CORSIM INPUT: Record types used and description

The code used for simulating the freeway in CORSIM is provided in APPENDIX A. A discussion on important entries in the code is provided.

1. Record Type 01: Run Identification: Name of person coding the network and date are entered using this record.
2. Record Type 02: Run Control: FRESIM Point Processing is desired and hence entry 2 is set to 1. This is necessary in order to obtain detector output in the .OUT file. The maximum initialization time is set to 15 minutes.
3. Record Type 03: Time period Specification: The simulation is performed for 60 minutes, hence, entry 1 is coded as 3600 seconds.

4. Record Type 04: Time intervals and Time Steps per Time Period: Entry 2 is coded as 60 seconds, which is the default value.
5. Record Type 05: Reports: Time to begin the first set of reports is 0 and duration of first reporting period is 3600 seconds. The time between each intermediate set of reports is 300 seconds (5 minutes).
6. Record Type 19: Freeway Link Geometry: 3 lanes are used throughout the freeway segment.
7. Record Type 20: Freeway Link Operation: A free flow speed of 65 mph is specified.
8. Record Type 25: Freeway Turn Movements: All vehicles are coded as through vehicles
9. Record Type 28: Surveillance Specification: This record allows the simulation of surveillance system. Using this record, detectors were placed at the beginning and end of the freeway segment. The detector type used was coupled pair of short loops with 6 ft spacing.
10. Record Type 50: Entry Link Volumes: The volume entering at node 1 of the network is coded in this record. The volume is varied for different runs of the simulation.
11. Record Type 64: Point Processing Specification: Output is requested at 5 minute intervals from the detectors by the use of this record. Average vehicle length is assumed to be 17 feet.
12. Record Type 67: Point Processing Station Numbers: The stations from which point processing output is desired is specified using this record.

The results of comparison of the model and actual travel times are provided now.

A) A uniform flow rate of 3000 vph is allowed on to the freeway in the first case for 1hour. The output from the detectors was observed to be as shown below:

Time	Station		sity	Station	Flow	Density
8:05	1	1000	24.25	6	988	12.14
8:10	1	1000	24.13	6	1004	12.66
8:15	1	1000	24.50	6	1024	12.61
8:20	1	1000	24.66	6	984	12.13
8:25	1	1000	24.29	6	1024	12.88
8:30	1	1000	24.60	6	976	12.23
8:35	1	1000	24.27	6	980	12.16
8:40	1	1000	24.77	6	1008	12.56
8:45	1	1000	24.68	6	1004	12.54
8:50	1	1000	24.40	6	992	12.52
8:55	1	1000	23.58	6	1028	12.98
9:00	1	1000	24.45	6	1012	12.57

Table 4.3: Detector Output for 3000vph

The densities shown in the above table are calculated from the occupancies given by the detectors by using the relationship

$$K = 52.8\ (\%OCC) / (L_V + L_D) = 2.3 * (\%OCC)$$

using Average Length of Vehicle $L_V = 17$ ft, Length of Detection Zone $L_D = 6$ ft.

Travel times from detector output are calculated using a spreadsheet. Actual travel times are also obtained from individual vehicles in CORSIM.

Time	Travel Time (Algorithm CASE C)	Travel Time (CORSIM)	Absolute Error	Squared Error
8:05	6.577	5.774	0.802	0.644
8:10	6.613	5.693	0.919	0.845
8:15	6.628	5.726	0.901	0.812
8:20	6.657	5.707	0.950	0.902
8:25	6.635	5.759	0.877	0.769
8:30	6.682	5.755	0.927	0.858
8:35	6.602	5.700	0.902	0.813
8:40	6.701	5.774	0.928	0.860
8:45	6.691	5.772	0.919	0.845
8:50	6.665	5.758	0.906	0.821
8:55	6.516	5.667	0.849	0.721

Table 4.4: Travel Time Estimation under no-incident no-closure case with 3000 vph

The mean absolute error (MAE) is 0.898 min and the Mean Squared Error is 0.808 minutes^2.

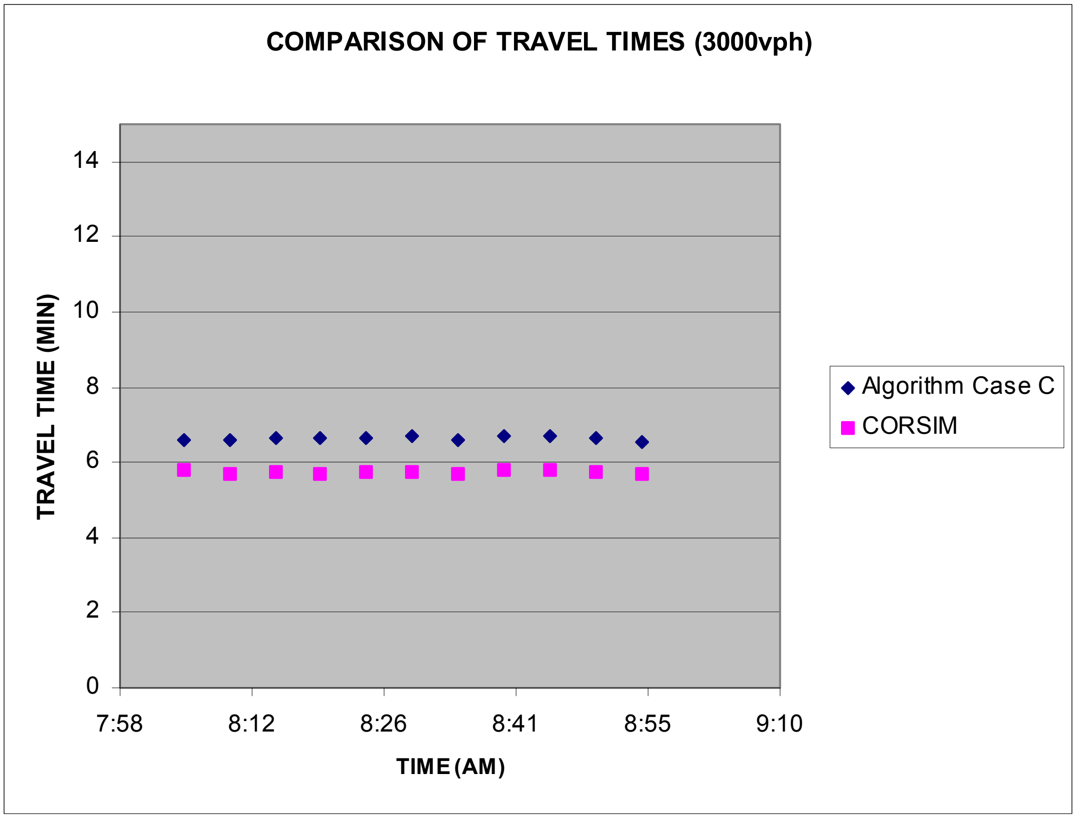


Figure4.6: Comparison of Travel times in Case C with 3000 vph

The procedure is repeated for cases with flows of 4000 vph and 5000 vph.

The results are as follows

B) With 4000vph: The flows and densities at the detectors averaged to single lane values are shown below.

Time	Station	Flow (vphpl)	Density (vpmpl)	Station	Flow (vphpl)	Density (vpmpl)
8:05	1	1332	31.71	6	1364	17.48
8:10	1	1332	31.87	6	1292	16.32
8:15	1	1336	31.67	6	1372	17.53
8:20	1	1332	31.57	6	1328	17.06
8:25	1	1332	31.14	6	1316	16.68
8:30	1	1332	31.78	6	1372	17.48
8:35	1	1336	31.66	6	1308	16.58
8:40	1	1332	31.61	6	1364	17.46
8:45	1	1336	31.68	6	1336	16.74
8:50	1	1332	31.26	6	1356	17.15
8:55	1	1332	31.95	6	1260	15.97
9:00	1	1336	31.63	6	1340	16.96

Table4.5: Detector Output for Case C with 4000 vph

The Travel Times from the algorithm and individual vehicle travel times are as follows

Time	Travel Time (Algorithm Case C)	Travel Time CORSIM	Absolute Error	Sqared Error
8:05	6.592	5.838	0.754	0.568
8:10	6.581	5.839	0.742	0.550
8:15	6.567	5.843	0.724	0.524
8:20	6.579	5.879	0.699	0.489
8:25	6.489	5.812	0.676	0.458
8:30	6.587	5.855	0.732	0.536
8:35	6.547	5.864	0.682	0.466
8:40	6.576	5.791	0.785	0.616
8:45	6.525	5.830	0.695	0.483
8:50	6.501	5.856	0.645	0.416
8:55	6.600	5.860	0.739	0.546

Table 4.6: Travel Time Estimation under no-incident no-closure case with 4000 vph

The mean absolute error is MAE = 0.715 min and the mean squared error is 0.514 minutes^2

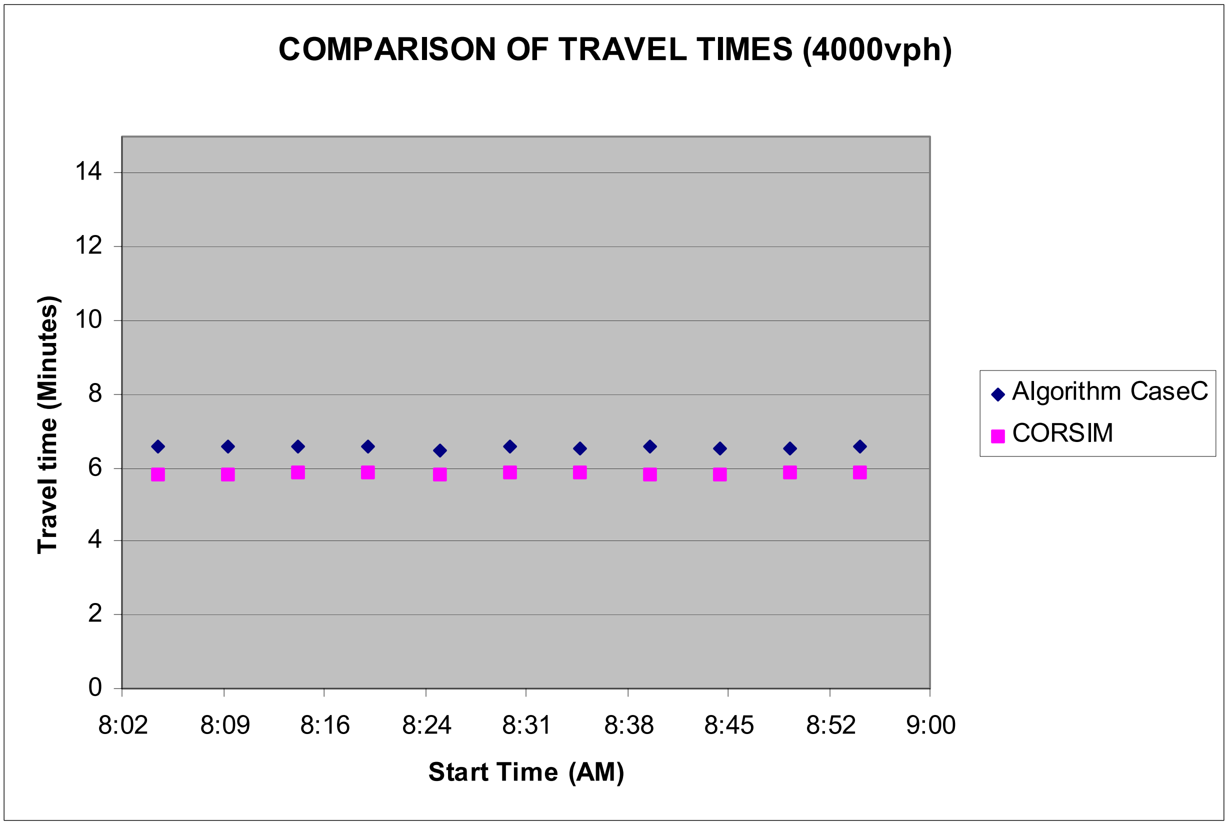


Figure4.7: Comparison of Travel times in Case C with 4000 vph

C) With 5000 vph: The flows and densities at the detectors averaged to single lane values are shown below.

Time	Station	Flow	Density	Station	Flow	Density
8:05	1	1660	39.71	6	1664	21.41
8:10	1	1668	39.99	6	1620	20.72
8:15	1	1668	40.17	6	1664	21.24
8:20	1	1664	40.22	6	1704	21.67
8:25	1	1668	39.64	6	1668	21.33
8:30	1	1668	40.03	6	1676	21.23
8:35	1	1664	40.34	6	1648	21.06
8:40	1	1668	39.85	6	1644	20.94
8:45	1	1664	40.27	6	1704	21.96
8:50	1	1668	40.28	6	1712	21.76
8:55	1	1668	40.78	6	1604	20.47
9:00	1	1668	40.11	6	1660	21.21

Table4.7: Detector Output for Case C with 5000 vph

The Travel Times from the algorithm and individual vehicle travel times are as follows

Time	Travel Time (Algorithm Case C)	Travel Time CORSIM	Absolute Error	Squared Error
8:05	6.623	5.943	0.680	0.463
8:10	6.618	5.973	0.645	0.416
8:15	6.633	5.918	0.716	0.512
8:20	6.640	5.933	0.707	0.500
8:25	6.580	5.931	0.649	0.421
8:30	6.600	5.904	0.697	0.485
8:35	6.664	5.915	0.749	0.560
8:40	6.593	5.974	0.619	0.383
8:45	6.676	5.936	0.740	0.547
8:50	6.635	5.957	0.677	0.459
8:55	6.698	5.942	0.756	0.571

Table4.8: Travel Time Estimation under no-incident no-closure case with 5000 vph

The Mean Absolute Error is 0.693 min and the Mean Squared Error is 0.483 minutes^2.

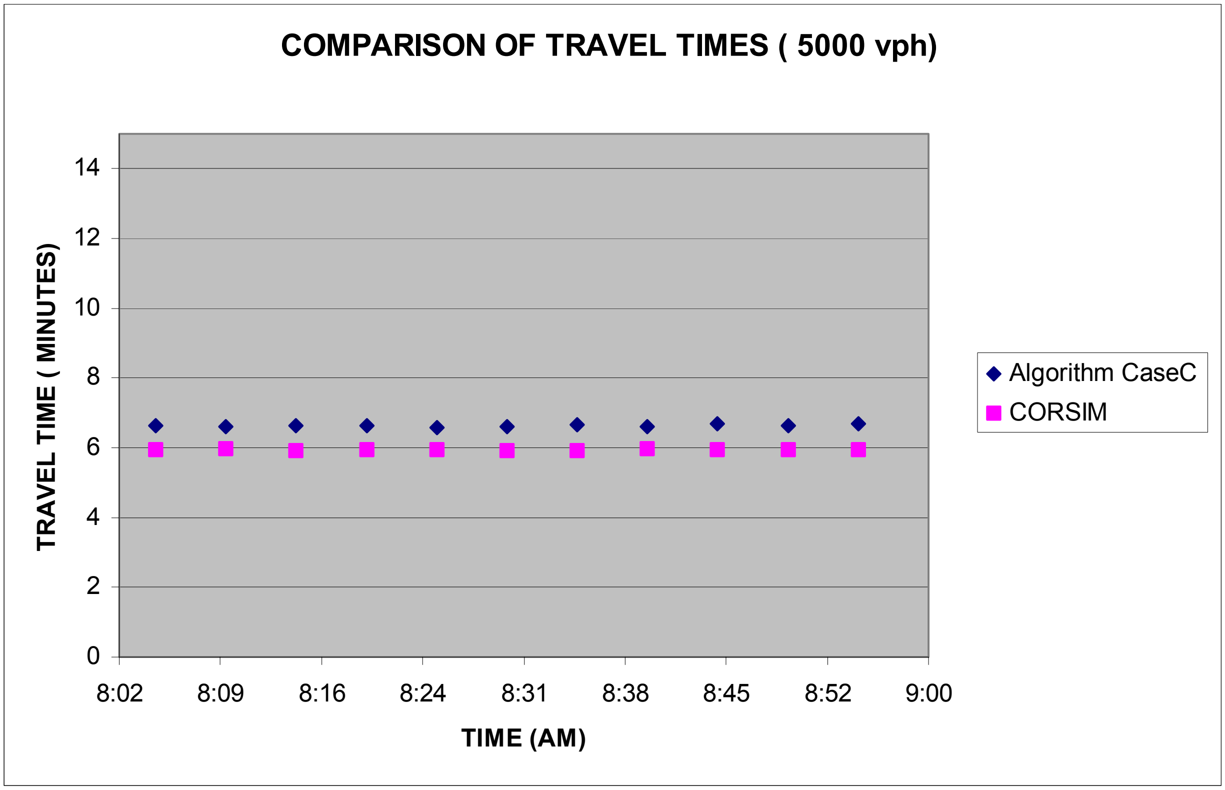


Figure4.8: Comparison of Travel times in Case C with 5000 vph

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Travel time estimation is very important for Advanced Traveler Information Systems. Travel time is also a good network performance measure. The thesis presented a comprehensive system for travel time estimation on urban freeways for ATIS applications. The system is tested by comparing the results with CORSIM and it is found give satisfactory performance under all traffic conditions.

Surveillance technologies are gaining increased usage on urban freeways. Most of these technologies provide flows and densities on freeways as output. A method for calculating travel times from this output will be the most economic method for ATIS implementation purposes in comparison to vehicle probes, GPS, AVI, Video detection and other technologies. A review of literature on travel time estimation techniques revealed a dearth of comprehensive procedures for travel time estimation on urban networks. The available methods for travel time estimation do not give satisfactory results under incident conditions or lane closures. The methods proposed by Nam and Drew (1996) for travel time estimation under normal traffic flow conditions as well as the method proposed by Daganzo et al (1997) for travel time estimation under lane closures are difficult to implement in real time. The former is very sensitive to errors in measurement, and loop detectors are notorious for their errors in measurement. The latter needs development and maintenance of huge databases, as information of arrival time of each vehicle is required to use the method. There is a tradeoff between accuracy and practicality in real world.

For ATIS purposes, a system that is easy to implement and not very data hungry is ideal, and a reasonable accuracy would suffice. The system should work under lane closures and incident conditions as well. The system provided in this thesis addresses these concerns. The system provided is relatively easy to implement in real-time and works under bottleneck conditions and under incident conditions. The accuracy of the system is quite satisfactory in all cases. The backbone of the system is the travel time estimation procedure under bottleneck conditions. It is reused in the travel time estimation under incident conditions. The system utilizes a comprehensive incident database to quickly estimate clearance times of incidents. This information can be broadcast to the road users apart from the travel time information to induce drivers to change routes suitably. A procedure for dynamic calculation of clearance times of incidents is provided. The procedure for travel time estimation under no incident and no closure case takes into account, the various conditions of traffic that may occur on freeways including normal, undisturbed flow and recurring congestion due to excess demand.

5.2 RECOMMENDATIONS

The system presented in the thesis assumes constant rates of discharge from bottlenecks. This assumption gives good results and makes implementation easier. However, the rate at which the bottlenecks discharge traffic has been a topic of research. Accurate estimates of discharge rates of bottlenecks are necessary to properly estimate delays and travel times.

For ATIS purposes, a framework as discussed in this thesis needs to be utilized for travel time estimations. There is a need for comprehensive systems for travel time estimation and future research needs to be directed to address this need.

Simulation software like CORSIM can have provisions to run probe vehicles to calculate travel times. Right now, the .TSD output file needs to be opened and read with external programs to get this information and this is a tedious process.

The working of the system under lane closures, incidents and in absence of these needs be tested in real time. Predicted volumes from Neural Networks and other methods can be used in the system to predict travel times. Further research is needed to explore these possibilities.

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APPENDIX A

CORSIM CODE FOR CASE A (LANE CLOSURE)

```
Thesis file 3 lane freeway with lane closure                                  00
12345678901234567890123456789012345678901234567890123456789012345678901234567800
         10        20        30        40        50        60        70        00
Sudheer Dhulipala                     04  17  02                               1
       1   1      15                               8 800        7781    7581   2
7200                                                                           3
                  60                                                           4
           07200 300                                                           5
8001   1   2     0 3                         1                                19
   1   2   3 52800 3                         1                                19
   2   3   4 52800 3                         1                                19
   3   4   5 52800 3                         1                                19
   4   5   6 52800 3                         1                                19
   5   6   7 52800 3                         1                                19
   6   78002 52800 3                         1                                19
8001   1         1  65                                                        20
   1   2         1  65                                                        20
   2   3         1  65                                                        20
   3   4         1  65                                                        20
   4   5         1  65                                                        20
   5   6         1  65                                                        20
   6   7         1  65                                                        20
   1   2   3 100                                                              25
   2   3   4 100                                                              25
   3   4   5 100                                                              25
   4   5   6 100                                                              25
   5   6   7 100                                                              25
   1   2   1   1  06       1   0                                              28
   1   2   2   1  06       1   0                                              28
   1   2   3   1  06       1   0                                              28
   1   2   11320  06       1   1                                              28
   1   2   21320  06       1   1                                              28
   1   2   31320  06       1   1                                              28
   1   2   12640  06       1   2                                              28
   1   2   22640  06       1   2                                              28
   1   2   32640  06       1   2                                              28
   1   2   13860  06       1   3                                              28
   1   2   23860  06       1   3                                              28
   1   2   33860  06       1   3                                              28
   1   2   15279  06       1   4                                              28
   1   2   25279  06       1   4                                              28
   1   2   35279  06       1   4                                              28
   2   3   11320  06       1   5                                              28
   2   3   21320  06       1   5                                              28
   2   3   31320  06       1   5                                              28
   2   3   12640  06       1   6                                              28
   2   3   22640  06       1   6                                              28
   2   3   32640  06       1   6                                              28
   2   3   13860  06       1   7                                              28
   2   3   23860  06       1   7                                              28
   2   3   33860  06       1   7                                              28
   2   3   15279  06       1   8                                              28
   2   3   25279  06       1   8                                              28
   2   3   35279  06       1   8                                              28
   3   4   11320  06       1   9                                              28
   3   4   21320  06       1   9                                              28
   3   4   31320  06       1   9                                              28
   3   4   12640  06       1  10                                              28
   3   4   22640  06       1  10                                              28
   3   4   32640  06       1  10                                              28
   3   4   13860  06       1  11                                              28
   3   4   23860  06       1  11                                              28
   3   4   33860  06       1  11                                              28
   3   4   14779  06       1  12                                              28
   3   4   24779  06       1  12                                              28
   3   4   34779  06       1  12                                              28
```

```
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   4   5   21320  06       1  13                                              28
   4   5   31320  06       1  13                                              28
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   4   5   22640  06       1  14                                              28
   4   5   32640  06       1  14                                              28
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   4   5   23860  06       1  15                                              28
   4   5   33860  06       1  15                                              28
   4   5   15279  06       1  16                                              28
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   4   5   35279  06       1  16                                              28
   5   6   15279  06       1  17                                              28
   5   6   25279  06       1  17                                              28
   5   6   35279  06       1  17                                              28
   6   7   15273  06       1  18                                              28
   6   7   25273  06       1  18                                              28
   6   7   35273  06       1  18                                              28
   3   4 2                       4460    820      1 7200                      29
8001   15000                                                                  50
8001   15000   02800  45                                                   1  53
  10   0 300                                          17   1                  64
 1 2 3 4 5 6 7 8 910111213141516                                              67
   0                                                                         170
   1    1200    600                                                          195
   2    6480    600                                                          195
   3   11760    600                                                          195
   4   17040    600                                                          195
   5   22320    600                                                          195
   6   27600    600                                                          195
   7   32800    600                                                          195
8001     600    600                                                          195
8002   33490    600                                                          195
   1                                                                         210
```

CORSIM CODE FOR CASE B (INCIDENT)

```
Thesis file 3 lane freeway with incident                                     00
12345678901234567890123456789012345678901234567890123456789012345678901234567800
         10        20        30        40        50        60        70        00
Sudheer Dhulipala                     04  16  02                               1
       1   1      15                               8 800        7781    7581   2
7200                                                                           3
                  60                                                           4
          07200 300                                                            5
8001   1   2     0 3                         1                                19
   1   2   3 52800 3                         1                                19
   2   3   4 52800 3                         1                                19
   3   4   5 52800 3                         1                                19
   4   5   6 52800 3                         1                                19
   5   6   7 52800 3                         1                                19
   6   78002 52800 3                         1                                19
8001   1         1  65                                                        20
   1   2         1  65                                                        20
   2   3         1  65                                                        20
   3   4         1  65                                                        20
   4   5         1  65                                                        20
   5   6         1  65                                                        20
   6   7         1  65                                                        20
   1   2   3 100                                                              25
   2   3   4 100                                                              25
   3   4   5 100                                                              25
   4   5   6 100                                                              25
   5   6   7 100                                                              25
   1   2   1   1  06       1   0                                              28
   1   2   2   1  06       1   0                                              28
   1   2   3   1  06       1   0                                              28
   1   2   11320  06       1   1                                              28
   1   2   21320  06       1   1                                              28
   1   2   31320  06       1   1                                              28
   1   2   12640  06       1   2                                              28
   1   2   22640  06       1   2                                              28
   1   2   32640  06       1   2                                              28
   1   2   13860  06       1   3                                              28
   1   2   23860  06       1   3                                              28
   1   2   33860  06       1   3                                              28
   1   2   15279  06       1   4                                              28
   1   2   25279  06       1   4                                              28
   1   2   35279  06       1   4                                              28
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   2   3   21320  06       1   5                                              28
   2   3   31320  06       1   5                                              28
   2   3   12640  06       1   6                                              28
   2   3   22640  06       1   6                                              28
   2   3   32640  06       1   6                                              28
   2   3   13860  06       1   7                                              28
   2   3   23860  06       1   7                                              28
   2   3   33860  06       1   7                                              28
   2   3   15279  06       1   8                                              28
   2   3   25279  06       1   8                                              28
   2   3   35279  06       1   8                                              28
   3   4   11320  06       1   9                                              28
   3   4   21320  06       1   9                                              28
   3   4   31320  06       1   9                                              28
   3   4   12640  06       1  10                                              28
   3   4   22640  06       1  10                                              28
   3   4   32640  06       1  10                                              28
   3   4   13860  06       1  11                                              28
   3   4   23860  06       1  11                                              28
   3   4   33860  06       1  11                                              28
   3   4   14779  06       1  12                                              28
   3   4   24779  06       1  12                                              28
   3   4   34779  06       1  12                                              28
```

```
   4   5   11320  06       1  13                                              28
   4   5   21320  06       1  13                                              28
   4   5   31320  06       1  13                                              28
   4   5   12640  06       1  14                                              28
   4   5   22640  06       1  14                                              28
   4   5   32640  06       1  14                                              28
   4   5   13860  06       1  15                                              28
   4   5   23860  06       1  15                                              28
   4   5   33860  06       1  15                                              28
   4   5   15279  06       1  16                                              28
   4   5   25279  06       1  16                                              28
   4   5   35279  06       1  16                                              28
   5   6   15279  06       1  17                                              28
   5   6   25279  06       1  17                                              28
   5   6   35279  06       1  17                                              28
   6   7   15273  06       1  18                                              28
   6   7   25273  06       1  18                                              28
   6   7   35273  06       1  18                                              28
   3   4 2                       4460    820      1 2700         4400         29
8001   15000                                                                  50
8001   15000   02800  45                                                   1  53
  10   0 300                                          17   1                  64
 1 2 3 4 5 6 7 8 9101112131415161718                                          67
   0                                                                         170
   1    1200     600                                                         195
   2    6480     600                                                         195
   3   11760     600                                                         195
   4   17040     600                                                         195
   5   22320     600                                                         195
   6   27600     600                                                         195
   7   32800     600                                                         195
8001     600     600                                                         195
8002   33490     600                                                         195
   1                                                                         210
```

CORSIM CODE FOR CASE C (NO-INCIDENT NO-CLOSURE)

```
Thesis file 3 lane freeway without incident or lane closure                   00
12345678901234567890123456789012345678901234567890123456789012345678901234567 00
        10        20        30        40        50        60        70        00
Sudheer Dhulipala                     04  15  02                               1
       1   1      15                               8 800        7781    7581   2
3600                                                                           3
                  60                                                           4
           03600 300                                                           5
8001   1   2     0 3                         1                                19
   1   2   3 52800 3                         1                                19
   2   3   4 52800 3                         1                                19
   3   4   5 52800 3                         1                                19
   4   5   6 52800 3                         1                                19
   5   6   7 52800 3                         1                                19
   6   78002 52800 3                         1                                19
8001   1         1  65                                                        20
   1   2         1  65                                                        20
   2   3         1  65                                                        20
   3   4         1  65                                                        20
   4   5         1  65                                                        20
   5   6         1  65                                                        20
   6   7         1  65                                                        20
   1   2   3 100                                                              25
   2   3   4 100                                                              25
   3   4   5 100                                                              25
   4   5   6 100                                                              25
   5   6   7 100                                                              25
   1   2   1   1  06       1   1                                              28
   1   2   2   1  06       1   1                                              28
   1   2   3   1  06       1   1                                              28
   1   2   13000  06       1   2                                              28
   1   2   23000  06       1   2                                              28
   1   2   33000  06       1   2                                              28
   2   3   13000  06       1   3                                              28
   2   3   23000  06       1   3                                              28
   2   3   33000  06       1   3                                              28
   3   4   13000  06       1   4                                              28
   3   4   23000  06       1   4                                              28
   3   4   33000  06       1   4                                              28
   4   5   13000  06       1   5                                              28
   4   5   23000  06       1   5                                              28
   4   5   33000  06       1   5                                              28
   6   7   15273  06       1   6                                              28
   6   7   25273  06       1   6                                              28
   6   7   35273  06       1   6                                              28
8001   14000                                                                  50
  10   0 300                                          17   1                  64
 1 2 3 4 5 6                                                                  67
   0                                                                         170
   1    1200     600                                                         195
   2    6480     600                                                         195
   3   11760     600                                                         195
   4   17040     600                                                         195
   5   22320     600                                                         195
   6   27600     600                                                         195
   7   32800     600                                                         195
8001     600     600                                                         195
8002   33490     600                                                         195
   1                                                                         210
```

APPENDIX B

PROGRAMS TO READ .TSD FILE AND CALCULATE TRAVEL TIMES

```
/* --------------------------------------------------------------------
  Name of the file: BIN_TO_ASCII.CPP
  This C++ File was created to read the output from the Binary .tsd file that
  is generated by TSIS and convert it into an ASCII readable format.
  ----------------------------------------------------------------------*/

#include <stdio.h>
#include <stdlib.h>
#include <fcntl.h>
#include <io.h>
#include<fstream.h>
#include<string.h>
#include<math.h>

/**
*       The basic functions that will be used are declared
*       GetMsgInfo()  : Used to read the Message Info to determine the type of message.
*       GetVehMsg()         : Used to read message if the Message Type is Vehicle
Message
*       CompVehInfo()       : Used to Compare the vehicle Info
*       ReadFile()          : Used to read the binary .TSD file
*/

void GetMsgInfo();
void CompMsgInfo();
void GetVehMsg();
void CompVehInfo();
void ReadFile();

int inhandle, outhandle, bytes;

unsigned int msg_name;
unsigned int msg_length;
unsigned int sim_time;
unsigned int inst_id;
unsigned int inst_id_count;
unsigned int request_type;
unsigned int i,vehicle;
unsigned int nodea, nodeb, cnode;
unsigned int veh_id;
unsigned int lane_id;
int veh_pos;
unsigned int prev_usn;
int acc;
unsigned int vel;
unsigned int dest_node;
```

```
FILE *input, *output;
char file1[255],file2[255],outfile[255],out[255],tempchar;


unsigned int link_id,thru_code;

ifstream fin;
ofstream fout;

double htemp;
long hlink;
unsigned int hi,hlocation,hveh_id,htime_step;
int       haccel,hvelocity,hpos;
char hbuffer[70];


void main(int argc, char **argv)
{

          // read the first and the second arguments from commandline as
          // the file to read and write

          strcpy(file2,argv[1]);
          strcpy(file1,argv[2]);

          // check for errors with the filenames provided at the commandline

          if ((output=fopen(file1, "w"))==NULL)
          {
                    fprintf(stderr,"Error Opening Output File: %s \n", file1);
                    exit(1);
          }


          // check for errors with the filenames provided at the commandline

          if ((input=fopen(file2, "rb"))== NULL)
          {
                    fprintf(stderr, "Error Opening Input File: %s\n",file2);
                    exit(1);
          }
          inhandle=fileno(input);
          outhandle=fileno(output);
          ReadFile();
}
```

```
void ReadFile()
{
    // The actual scanning of file starts after the first 16 bytes.


    // The First 16 Bytes of the File Represent the Header Information
    lseek(inhandle, 16, SEEK_SET);

    // Keep reading data untile the end of file is reached
    while (!eof(inhandle))
    {
        // First read the msg info into local variables for comparision
        GetMsgInfo();

        // check to see if this is the vehicle info to capture
        if (msg_name==3001&&request_type==14000)
        {
            // since vehicle message read number of vehicles in message and
            length
            CompVehInfo();

            // read all the vehicle snapshot in the message
            for (i=0;i<inst_id_count;i++)
            {
                // read individual vehicle message
                GetVehMsg();

                // write to output file

    fprintf(output,"%4u\t%4u\t%4u\t%4u\t%4u\t%8d\t%4u\t%6d\t%4u\t%4u\n",veh_
id,sim_time,inst_id/10000,inst_id-
(inst_id/10000)*10000,lane_id,veh_pos,prev_usn,acc,vel,dest_node);
            }
        }
        else
        CompMsgInfo();
        // goto next message if message info type is not vehicle
    }
}

void GetMsgInfo()
{
    // message info consists of
    // message_name of 4 bytes
    // message_len of 4 bytes
    // sim_time of 4 bytes
```

```
        // request_type of 4 bytes

        bytes = read(inhandle, &msg_name, 4);
        bytes = read(inhandle, &msg_length, 4);
        bytes = read(inhandle, &sim_time, 4);
        bytes = read(inhandle, &request_type, 4);
}

void CompVehInfo()
{

        // since we are not concerned with the first 28 bytes skip to the next
        lseek(inhandle, 28, SEEK_CUR);

        // read the important fields into local variables
        // inst_id_count represents how many vehicles wrapped into message
        bytes = read(inhandle, &inst_id,4);
        bytes = read(inhandle, &inst_id_count,2);
}

void CompMsgInfo()
{
        //skip to the next
        lseek(inhandle, msg_length-4, SEEK_CUR);
}

void GetVehMsg()
{
        // capture all the necessary attributes into local variables
        // for persistance into output file

        bytes = read(inhandle, &veh_id, 4);
        lseek(inhandle, 4, SEEK_CUR);
        bytes = read(inhandle, &lane_id, 1);
        bytes = read(inhandle, &veh_pos, 4);
        bytes = read(inhandle, &prev_usn, 2);
        lseek(inhandle, 2, SEEK_CUR);
        bytes = read(inhandle, &tempchar, 1);
        acc=tempchar;
        bytes = read(inhandle, &vel, 1);
        lseek(inhandle, 2, SEEK_CUR);
        bytes = read(inhandle, &dest_node, 2);
        lseek(inhandle, 9, SEEK_CUR);
}
```

```
/* -----------------------------------------------------------------------------------------------------
  Name of the File : TTCORSIM.CPP
  This program calculates travel times from the sorted .tsd file in ASCII format.
  This program is run after sorting the ASCII file generated by CORCONV.EXE
  TTCORSIM.EXE takes two arguments: The input file name and the output file name
-----------------------------------------------------------------------------------------------------*/

#include<fstream>
#include<iostream.h>
#include <string>
//Define TIME to be 1 + Simulation Time in seconds. This is used in array creation
#define TIME 7201
using namespace std;

char file1[255],file2[255];
void main(int argc, char **argv)
{

        // read the first and the second arguments from commandline as
        // the file to read and write

        strcpy(file2,argv[1]);
        strcpy(file1,argv[2]);
        ifstream In(file2);
        ofstream Out(file1);

        int veh[TIME], up[TIME], dwn[TIME], lane[TIME], vpos[TIME],
prevup[TIME];
        float acc[TIME], vel[TIME], dest[TIME], time[TIME];

        Out<<"Start             Travel Time             Distance"<<endl;

        int i=0;
        float tt = 0;
        // Priming read to abort if file reading fails
        In>>veh[i]>>time[i]>>up[i]>>dwn[i]>>lane[i]>>vpos[i]>>prevup[i]>>acc[i]>>v
el[i]>>dest[i];

while(In)
{
        i=i+1;
        In>>veh[i]>>time[i]>>up[i]>>dwn[i]>>lane[i]>>vpos[i]>>prevup[i]>>acc[i]>>v
el[i]>>dest[i];
```

```
                    /* If vehicle i and vehicle (i-1) do not have the same id, then we
                       calculate travel times by finding difference in start time and end time of
                       the vehicle*/

if (veh[i]!=veh[i-1])
{
        tt=time[i-1]-time[0];
        float distance = vpos[i-1]+(5280-vpos[0]) + (up[i-1]-up[0]-1)*5280;//in ft

        /* The 'if' condition that follows makes sure that only vehicles travelling
           more than 5.9 mi are written to the output file. This 'if' has to be removed if the
           travel times of all vehicles are desired. */
        if (distance/5280 >= 5.9)
        Out<<time[0]/60<<"   "<<tt * 6*5280/(distance*60)<<""<<distance/5280<<endl;

        // Reset the initial element in each array to the current vehicle information
        veh[0] = veh[i];
        time[0]=time[i];
        up[0]=up[i];
        dwn[0]=dwn[i];
        lane[0]=lane[i];
        vpos[0]=vpos[i];
        prevup[0]=prevup[i];
        acc[0]=acc[i];
        vel[0]=vel[i];
        dest[0]=dest[i];
        i=0;
}
}

        In.close();
        Out.close();
}
```

```
/*
  Name of the file: AVGTT.CPP
  This program averages the travel time output generated by TTCORSIM.EXE
  at 5 minute interval.
*/
#include<fstream>
#include<iostream.h>
#include <string>
#define MAXVEH 10000
using namespace std;

char file1[255],file2[255];
void main(int argc, char **argv)
{

        /* read the first and the second arguments from command line as
         the file to read and write*/

        strcpy(file2,argv[1]);
        strcpy(file1,argv[2]);

        ifstream In(file2);
        ofstream Out(file1);
        // Ignore the first line from the input file
        In.ignore(100,'\n');

        int i=0;

        float start[MAXVEH], tt[MAXVEH],dist[MAXVEH], sum=0, avg=0;
        // Initialize the arrays
        for (i=0; i<MAXVEH;i++)
        {
                start[i]=0;
                tt[i]=0;
                dist[i]=0;
        }

        i=0;
        int k=1;
        int flag =0, m=0;
        // Priming read to abort in case of file read error
        In>>start[i]>>tt[i]>>dist[i];
        sum=sum+tt[i];


        while(In)
```

```
        {

                i=i+1;
                In>>start[i]>>tt[i]>>dist[i];

                if (start[i]>5*k && start[i-1]<=5*k)
                {

                        avg=sum/(i-m);
                        Out<<start[i-1]<<"\t"<<avg<<endl;
                        sum=tt[i];
                        flag=1;
                        k=k+1;
                        m=i;
                }
                if(flag ==0)
                sum=sum+tt[i];
                flag=0;
        }
        // The last average is output now
        avg=sum/(i-m);
        Out<<start[i-1]<<"\t"<<avg<<endl;

        // The input and output files are closed
        In.close();
        Out.close();
}
```

Batch file for obtaining averaged 5 minute interval travel times from CORSIM .TSD file

The following file should be saved with .BAT extension in the same folder in which the .TSD file, CORCONV.EXE, TTCORISM.EXE, and AVGTT.EXE are located.
These .EXE files are generated by compiling the code given in the previous three files separately.

```
corconv noincident.tsd corout.txt
sort corout.txt /o sorted.txt
ttcorsim sorted.txt ttcorsim.txt
avgtt ttcorsim.txt avgtt.txt
```

C.BAT

The filename shown in bold should be changed to obtain averaged travel times for different simulation files. The final output will be written to avgtt.txt. In case a different file is needed this name may be changed in the batch file.

VITA

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