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Final Report

Development of Operational Strategies for Travel Time Estimation and Emergency Evacuation on a Freeway Network

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16. Abstract (Limit: 200 words)

This research studied the feasibility of applying a dynamic traffic assignment model, Dynasmart-P, for evaluating the effectiveness of alternative strategies for evacuating the traffic in downtown Minneapolis, Minnesota, under a hypothetical emergency situation that included the evacuation of the sell-out crowd in the Metrodome. For this study, the southwest portion of the Twin Cities metro area was selected as the study network and a set of different network configurations were evaluated in terms of their effectiveness in coping with a given emergency situation. The simulation results indicate that managing traffic conditions at the outbound freeway links in the given network during the evacuation period and the access capacity from the downtown area to those outbound freeway links are the critical factors affecting the effectiveness of evacuation operations. For example, the evacuation time under the contra-flow operations with the freeways surrounding the downtown area was substantially reduced when the capacities of the key entrance ramps were also increased. Further, an enhanced snap-shot-speed based, on-line travel time estimation strategy was developed and tested at the selected freeway corridors in the Twin Cities' metro freeway network. The off-line testing results of the proposed method showed acceptable performance during the traffic transition periods for the freeway sections up to 12-mile length.

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Development of Operational Strategies for Travel Time Estimation and Emergency Evacuation on a Freeway Network

Final Report

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EXECUTIVE SUMMARY

This research studied the feasibility of applying a dynamic traffic assignment model, Dynasmart-P, for evaluating the effectiveness of evacuation strategies on a large-scale urban network. The southwest portion of the Minneapolis-St. Paul metro network including downtown Minneapolis, Minnesota, was selected as the study network and a set of different network configurations was modeled and evaluated using Dynasmart-P for a hypothetical emergency situation involving the evacuation of the Metrodome crowd as well as the downtown traffic. The data for this analysis was obtained in cooperation with the Metro Council, the state-wide transportation planning agency, which provided the network geometry and time-variant origin/destination traffic demand data for the study network. The simulation results indicate that the access capacity to the outbound freeway network is the critical issue in reducing the evacuation time of the downtown traffic. For example, the improvements of the traffic capacity for the external freeway links without increasing the access capacity did not make any significant reduction of the evacuation time, while the effectiveness of the contra-flow operation with the outbound freeway links showed substantial improvements when the capacities of the key entrance ramps were also increased. The qualitative analysis of the simulation results from Dynasmart-P show promising possibilities of applying such a model for the evacuation analysis in a large network environment.

The second part of this research developed an on-line strategy to determine travel times for predefined freeway routes in real time. As part of this study, all the locations of the existing detector stations were identified and coded into the digital freeway network map. Further, the distance between two detector stations was also estimated. The off-line testing results of the modified version of the snap-shot-speed-based method showed acceptable performance with steady traffic conditions, either congested or uncongested, while its performance could be significantly degraded for a long freeway section, i.e., longer than 12 miles, during transition periods because of unexpected events, e.g., incidents, or sudden changes in traffic demand. An enhanced methodology to reduce the prediction error was also developed and tested in this research. It was noted that maintaining a high level of detection availability and accuracy is an essential element for providing accurate travel-time information in real time.

1. INTRODUCTION

Managing traffic operations during/after major emergency events, such as a terrorist attack or high consequence incidents, is one of the critical components in emergency management for effectively responding to, recovering from and mitigating the impacts of a disaster. The key elements for an effective emergency operation include the ability to determine the best set of evacuation routes and schedule for large-scale movement of people under time-sensitive, hazardous conditions. Such an evacuation strategy under threats from terrorists or WMD (Weapons of Mass Districtruction) needs to reflect various resources/constraints of transportation system networks at different levels, i.e., local and regional, under dynamically changing traffic and emergency conditions. Further, the capability to provide travel-time information to drivers for a given network would be essential in effectively managing traffic under emergency as well as normal congestion conditions.

To address the above needs, this research studies the feasibility of applying a new generation traffic-network planning model, Dynasmart-P, in developing and evaluating emergency evacuation strategies. This model, which has been developed under the sponsorship of Federal Highway Administration (FHWA), adopts a dynamic traffic assignment approach and is capable of determining time-variant link traffic conditions by reflecting the effects of various types of travel information/guidance strategies on a large network (Mahmassani, et. al., 2004). Further, a strategy to estimate travel times for selected routes in real time under the current Minnesota freeway management system is also developed. The specific objectives of this study include:

- Application of Dynasmart-P for developing and evaluating emergency evacuation strategies in the Minneapolis-St. Paul metro area in Minnesota (Part I),
- Development of an operational strategy to estimate travel time for predefined routes on a freeway network in real time under the current Mn/DOT freeway management system (Part II).

The Chapter 1 of this report describes the summary results of the Dynasmart-P application in modeling and evaluating a set of evacuation strategies using a hypothetical emergency situation in downtown Minneapolis, Minnesota. The detailed process for preparing input data files for Dynasmart-P for the study network, which covers the southwest quadrant of the metro area, is also included in Chapter 2. The development of an on-line strategy for providing travel time information in real time for pre-defined freeway routes is described in Chapter 3. Finally Chapter 4 summarizes conclusions and further research needs.

2. APPLICATION OF DYNASMART-P FOR EVACUATION ANALYSIS IN A LARGE NETWORK

2.1 Development of Emergency Scenarios for a Selected Network and Data Collection

The Metrodome, an indoor football/baseball facility located in downtown Minneapolis, Minnesota, frequently holds a professional sport event on a weekday or weekend in Fall and Spring every year. The example emergency scenario formulated in this research in consultation with the technical liaison involves the evacuation of the sell-out Metrodome crowd attending one weekday evening sport event. The evacuation demand from the Metrodome in a sell-out event was estimated as 25,000 vehicles, which are based on its seating capacity and, in this study, these vehicles are assumed to be distributed throughout the downtown area. To model and evaluate alternative evacuation scenarios involving the traffic to be generated from the Metrodome, the southwest portion of the Minneapolis-St. Paul metro network was selected as the study network for this analysis. The data for the selected network for modeling with Dynasmart-P have been collected in cooperation with the Metro Council. Figure 2.1.1 shows the sample network in the ArcView format provided by the Metro Council.

The data collected for the sample network includes the geometry of the network, i.e., coordinates of each node, direction and number of lanes in each link and link capacity. The selected network contains a total of 421 zones, which include both internal and external boundary zones. In particular, a set of time-variant traffic demands for each origin/destination zone pair in the study network was provided by the Metro Council for a normal weekday afternoon, i.e., 2:00 p.m to 10:00 p.m., for every 15 minute interval. The geometry data for the sample network is stored in an ArcView format, while the origin/destination traffic demand data are in a text mode.

2. 2 Modeling and Calibration of the Study Network with Dynasmart-P

Data Processing

The collected data were processed to develop a set of the input files to calibrate Dynasmart-P by modeling the sample network with the current conditions. Table 2.2.1 shows the list of the input data files required or optional by the current version of Dynasmart-P. First, a conversion software was developed to convert the network geometry data, i.e., coordinates of the nodes and directional links, stored in the ArcView format, to those required by Dynasmart-P. The conversion software was written in Java and takes the ArcView shape files for the sample network as an input and produces the network data files required by Dynasmart-P, including zone.dat, network.dat, linkxy.dat and xy.dat. The conversion software developed in this study was written in Java. The converted network in the Dynasmart-P format was further revised to correctly represent the current field network conditions, such as replacing intersections with interchanges and removing hypothetical connectors/centroids in the ArcView network. In addition, some of the boundary zones that share common roadways were aggregated for simplicity. The resulting network has a total of 387 zones, 2488 nodes and 5565 links. Figure 2.2.1 shows the study network coded in Dynasmart-P to model the afternoon traffic patterns, i.e., the existing barrier-separated High Occupancy Vehicle Lane section on the I-394 freeway are coded as the westbound links.

Figure 2.1.1 Original Sample Network stored in ArcView format

Table 2.2.1 List of Input Data Files for Dynasmart-P

File Name	Description	Req/Optional
bus.dat	information regarding the buses including the trajectories, location of stops, dwell time, etc	Optional
control.dat	type of traffic control at each node and phasing information, if the intersection is signalized	Required
demand.dat	temporal and spatial distribution of origin/destination demand	Required
destination.dat	destination nodes in each zone	Required
incident.dat	locations of road closures (incidents/work zone applications), severity, timing, etc	Optional
leftcap.dat	left-turn capacity at signalized intersections	Required
movement.dat	movements of vehicles (right turns, left turns, through, and others)	Required
network.dat	network configuration, zoning and link characteristics	Required
origin.dat	generation links in each zone	Required
output_option.dat	frequency of writing to output files	Required
path.dat	vehicle trajectory to be used in conjunction with vehicle.dat	Optional
pricing.dat	pricing on the HOT/HOV lanes	Optional
ramp.dat	ramp locations, detector locations, metering rate, and its timing	Optional
scenario.dat	Simulation parameters	Required
SuperZone.dat	mapping of zones to super zones	Optional
system.dat	election of the solution mode, length of the planning horizon, aggregation and assignment interval	Required
TrafficModel.dat	type of speed-density models specified and their corresponding parameters	Required
vehicle.dat	number of vehicles to be loaded	Optional
vms.dat	the location, type, and time of activation for variable message signs	Optional
WorkZone.dat	number of work zone links, duration, capacity reduction, new speed limit, and discharge rate	Optional
StopCap2Way.dat	capacity of approaches at two-way stop-controlled intersections	Required
StopCap4Way.dat	capacity of approaches at all-way stop-controlled intersections	Required
GradeLengthPCE	effect of grade length and truck percentage on Passenger Car Equivalent (PCE) factors	Required
linkname.dat	names of links (i.e. street names)	Optional
linkxy.dat	coordinates of feature points of each link including starting/ending nodes	Optional
xy.dat	coordinates of physical nodes	Optional
zone.dat	zone boundary data	Optional

The traffic demand data provided by the Metro Council was also modified for the revised network and most of other data files required for simulation, such as origin.dat and destination.dat, were manually generated. In particular, the movement.dat file, which specifies the allowed movements of traffic in each link, e.g., through, left and right-turns, was initially generated by using DynaBuilder, the utility software provided by the Dynasmart-P development group, but the resulting file needed to be checked and corrected manually since some of the geometry in the network could not be handled by DynaBuilder. Further, due to the limitations of the current version of Dynasmart-P in modeling signal control, all the intersections in the study network were assumed to be operated in the actuated mode and the Dynasmart-P generated control.dat file was used for this analysis. Figure 2.2.2 shows the data preparation process adopted in this study in developing the input files for Dynasmart-P.

Qualitative Calibration

Using the input data files prepared in the previous section, the study network was simulated with Dynasmart-P and some of the model parameters, such as link capacity and overall scale factor of the demand data, were adjusted to make the estimated flow patterns are similar to the observed traffic behavior at the key freeway locations where the loop-detector measurements were available. Figures 2.2.3-2.2.10 show the comparison results between the Dynasmart-P output and the field data collected on typical weekdays from three different seasons. Due to the limitations on time and resources, an extensive calibration could not be conducted in this study.

As indicated in those figures, the outputs from Dynasmart-P follow the trends of the traffic variations at those data collection locations. Further, the estimated traffic conditions by Dynasmart-P at the key bottlenecks in the network, such as the 62 westbound right before the merge point with the 35W northbound, also show significant congestion levels similar to generally observed patterns. It needs to be pointed out that in this calibration the demand data provided by the Metro Council for the origin/destination zones were used without extensive adjustments. In addition, only major arterial streets in the network were modeled with the simplified treatments of the signal control strategies, i.e., actuated mode, at all the intersections. Future study needs to address those issues, so that the current network environment can be modeled as realistically as possible. The limited calibration results conducted in this study indicate that the model could be calibrated to the acceptable level by systematically adjusting the origin/destination trip table with more realistic modeling of the signal control strategies.

Figure 2.2.1 The Study Network coded into Dynasmart

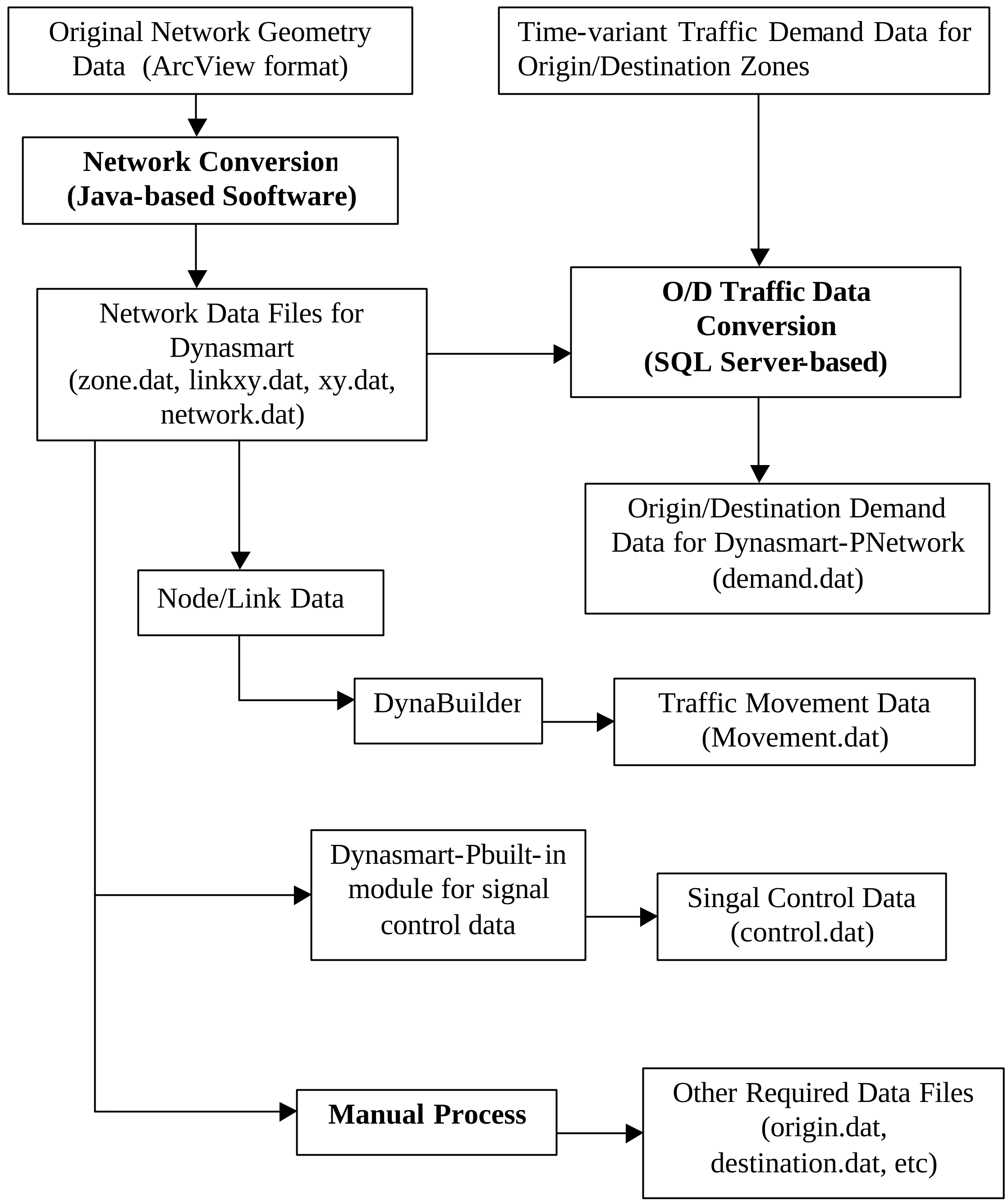

Figure 2.2.2 Input Data File Preparation Process for Dynasmart-P

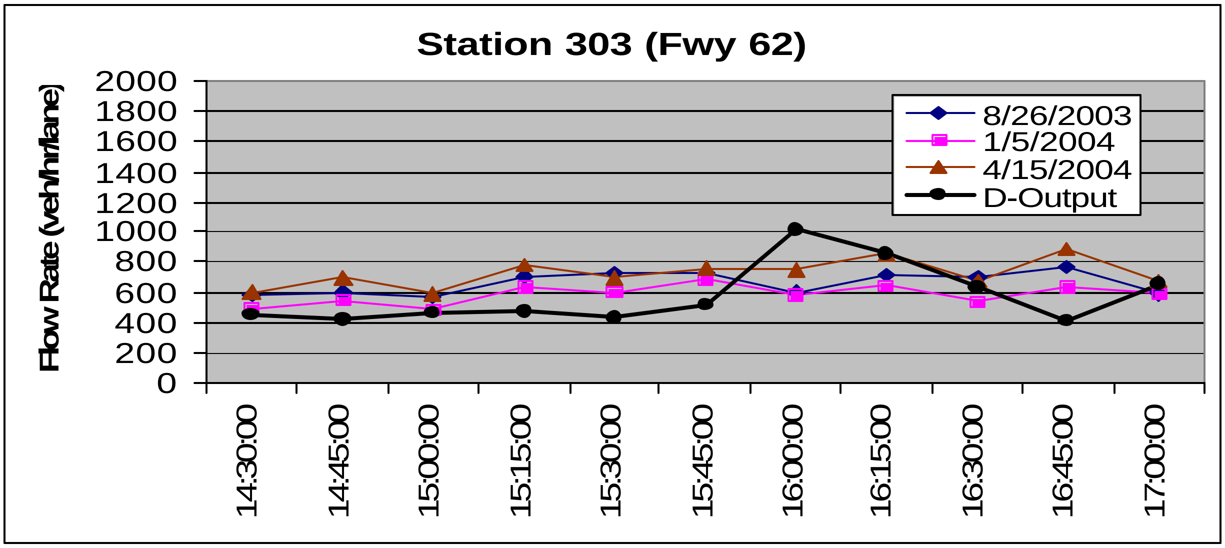

Figure 2.2.3 Comparison between Dynasmart-P output and field observations (station 303)

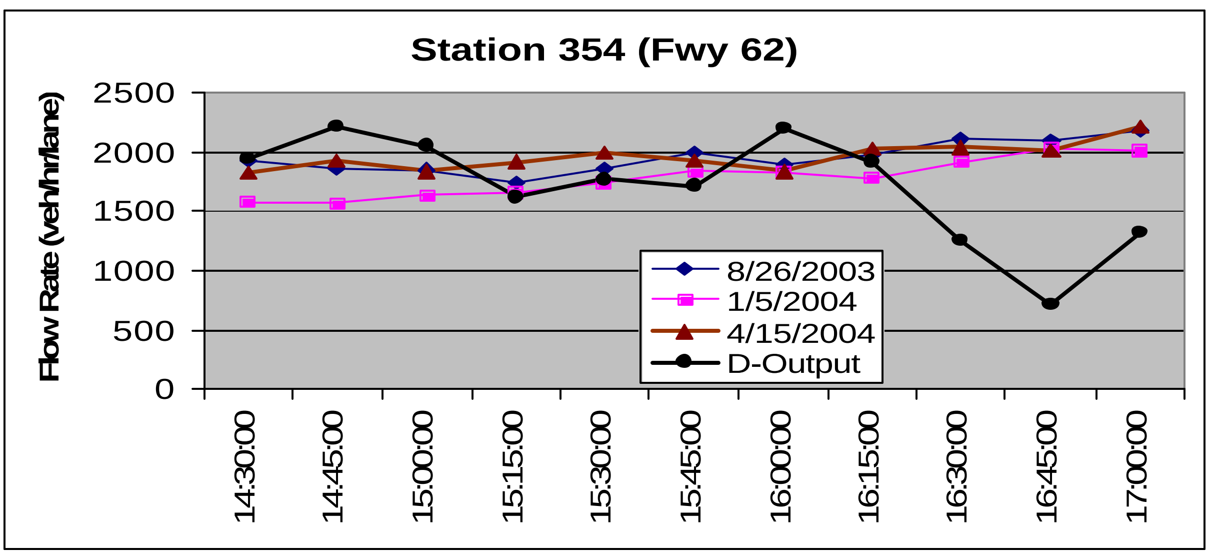

Figure 2.2.4 Comparison between Dynasmart-P output and field observations (station 354)

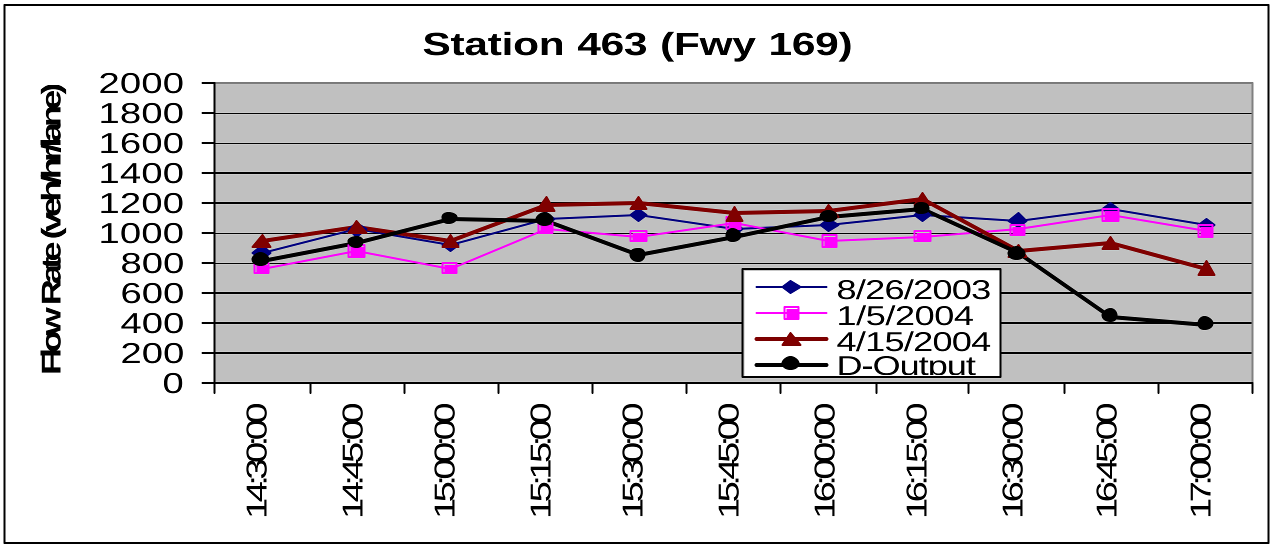

Figure 2.2.5 Comparison between Dynasmart-P output and field observations (station 463)

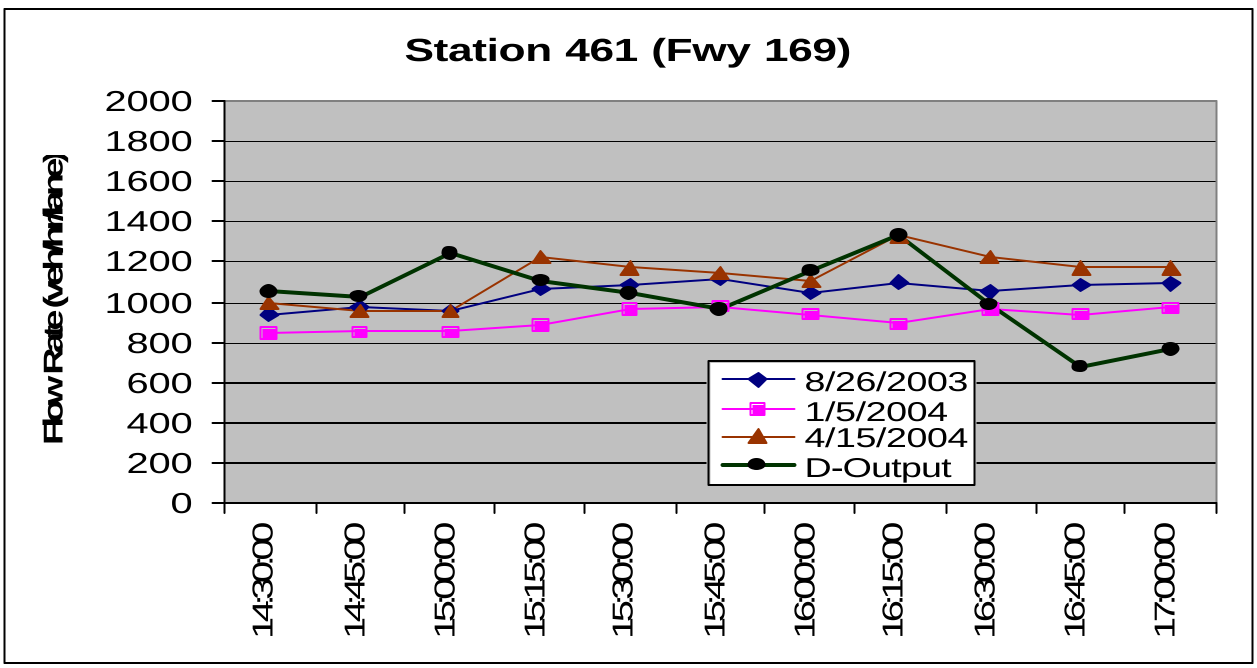

Figure 2.2.6 Comparison between Dynasmart-P output and field observations (station 461)

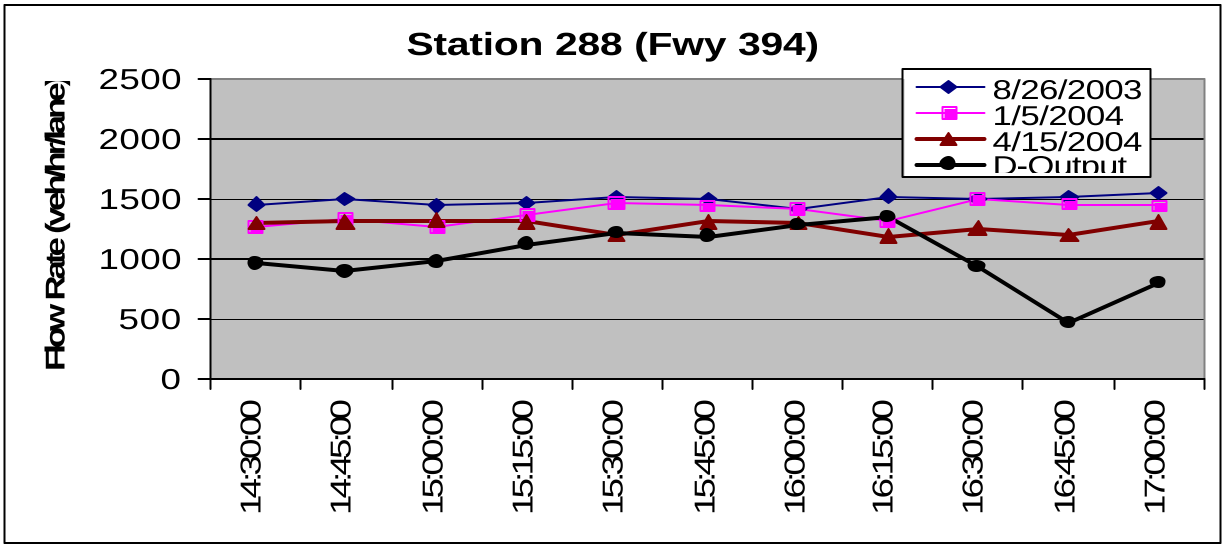

Figure 2.2.7 Comparison between Dynasmart-output and field observations (station 394)

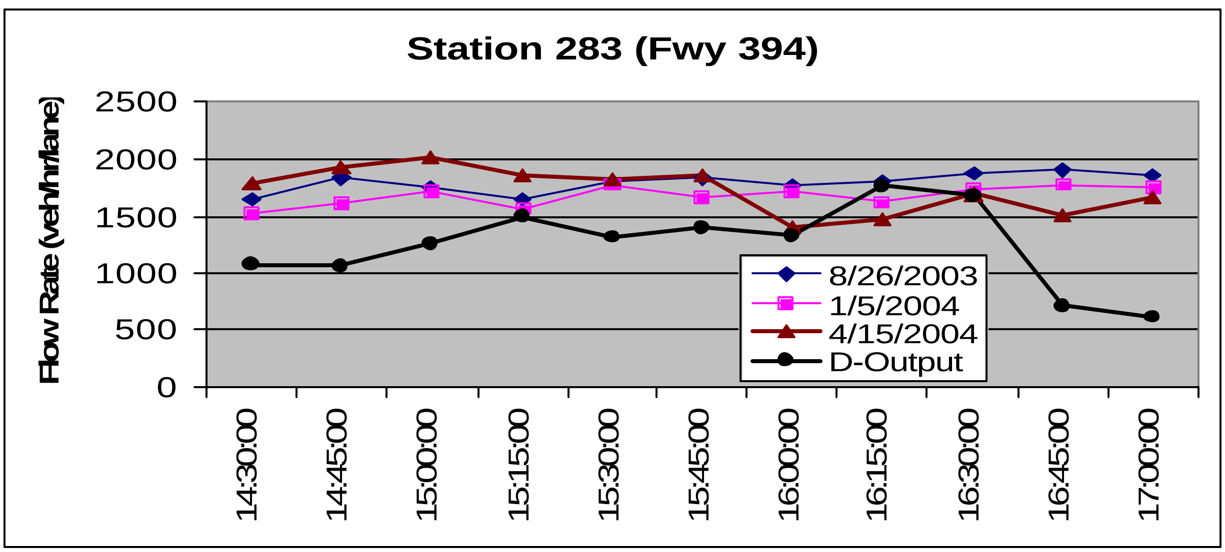

Figure 2.2.8 Comparison between Dynasmart-P output and field observations (station 283)

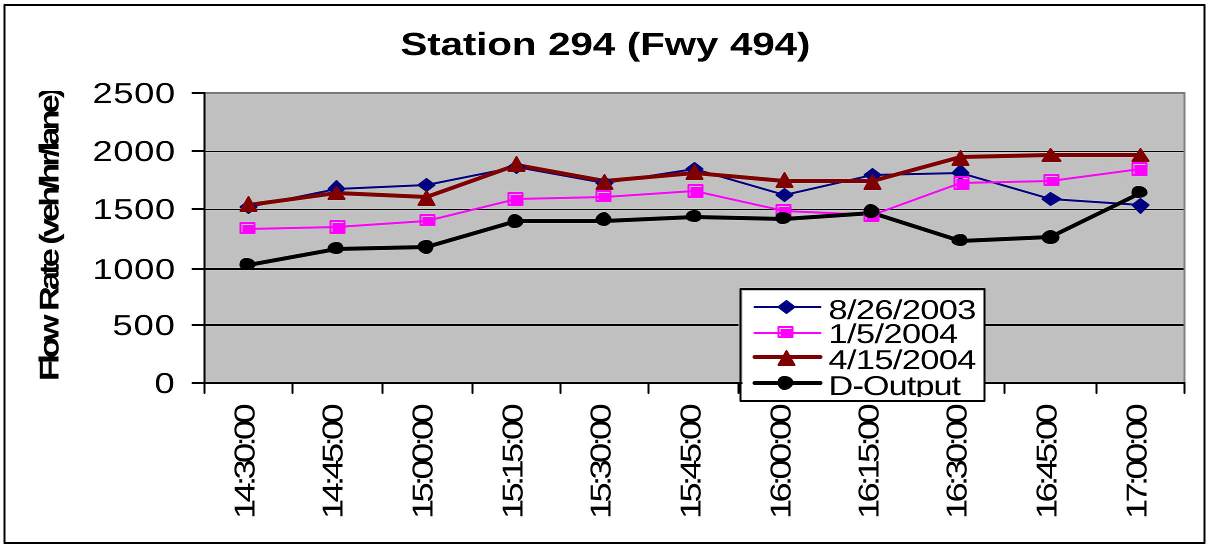

Figure 2.2.9 Comparison between Dynasmart-P output and field observations (station 294)

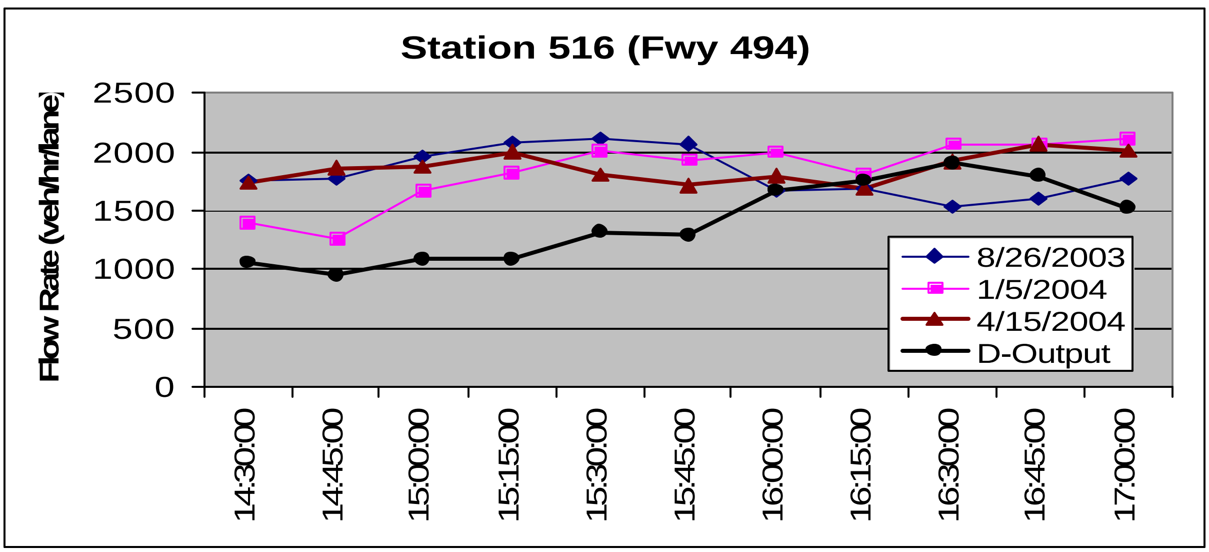

Figure 2.2.10 Comparison between Dynasmart-P output and field observations (station 516)

2.3 Development of Alternative Evacuation Strategies for Evaluation

Figure 2.3.1 shows the downtown zones, including the zone 130 where the Metrodome is located, which need to be evacuated in this study. As described earlier, the evacuation of the downtown zones is assumed to be started at 5:00 p.m., while the total simulation period for the evacuation analysis is from 4:00 p.m. until 7:00 p.m. The sum of the normal outbound trip demand for the two-hour period, i.e., from 5:00 p.m. to 7:00 p.m., originated from those evacuation zones was estimated as 7478 vehicle trips based on the trip demand data provided by the Metro Council. Since this number was considered somewhat lower than actual value, and also due to the lack of the evacuation demand data formally determined for the downtown area, in this simulation analysis, two sets of the evacuation demand were used to estimate the evacuation times under two extreme demand conditions, i.e.,

- Demand set #1: 25,000 + 7,478 = 32, 478 vehicle-trips (Metrodome + Other zones)
- Demand set #2: 25,000 + 15,000 = 40,000 vehicle-trips

The destination of the above evacuation demand is distributed to different zones in the study network following the 2000 Twin Cities population distribution (Metro Council, 2000) as follows:

- Northwest: 28%,
- Northeast: 17%,
- Southwest 30%,
- Southeast: 25%

It is further assumed that all the evacuation demand want to evacuate at the same time, i.e., at 5:00 p.m. when the evacuation starts. In terms of the network configurations during the evacuation, the following three alternatives were modeled and evaluated with Dynasmart-P:

#1: Only the arterial links and freeway exit ramps approaching the downtown area are blocked when evacuation starts (Figure 2.3.2).
#2: In addition to #1, the incoming freeway links located inside the network are blocked to prevent vehicles from approaching the evacuation area (Figure 2.3.3).
#3: In addition to #1, all the inbound/outbound freeway links in the inside network are converted to one-way outbound links, i.e., contra-flows, as shown in Figure 2.3.4.

In the above configurations, #2 is expected to provide more capacity to the outbound freeway links compared to #1 by blocking all the inbound freeway links to the downtown area, i.e., the outbound freeway links with #2 would have less traffic coming from other freeways than that with #1. It needs to be noted that the changes in the network configuration in the above three alternatives become effective when the evacuation starts, i.e., at 5:00 p.m. during the simulation.

Further, since Dynasmart-P does not provide a built-in function to simulate time-variant contra flows that need to be modeled in #3, the incident function of the current version was used to emulate the directional changes of the freeway link flows during the simulation. For example, the number of lanes in the outbound links was doubled initially with 50% capacity-reduction incidents until the evacuation started. When the contra flow operation starts, the outbound links start to

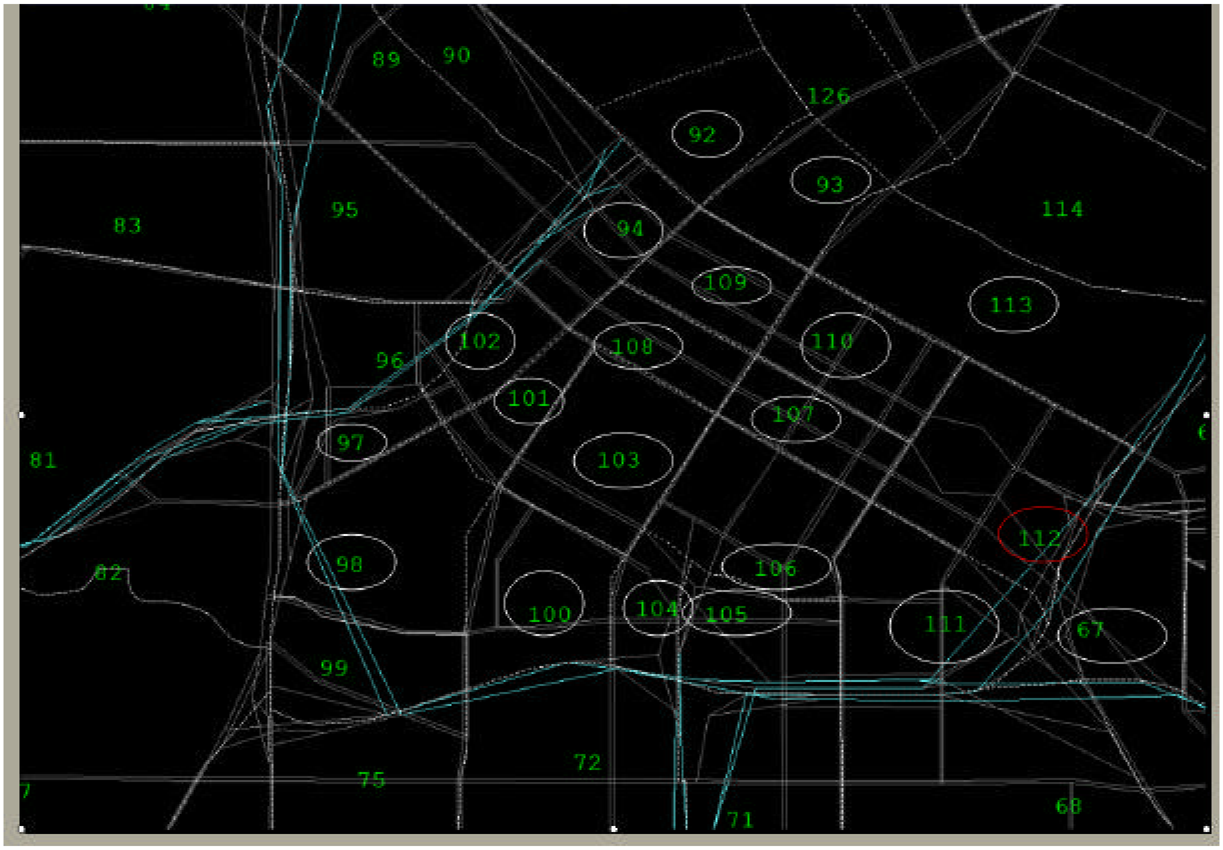

Figure 2.3.1 Downtown Zones (circled) to be evacuated

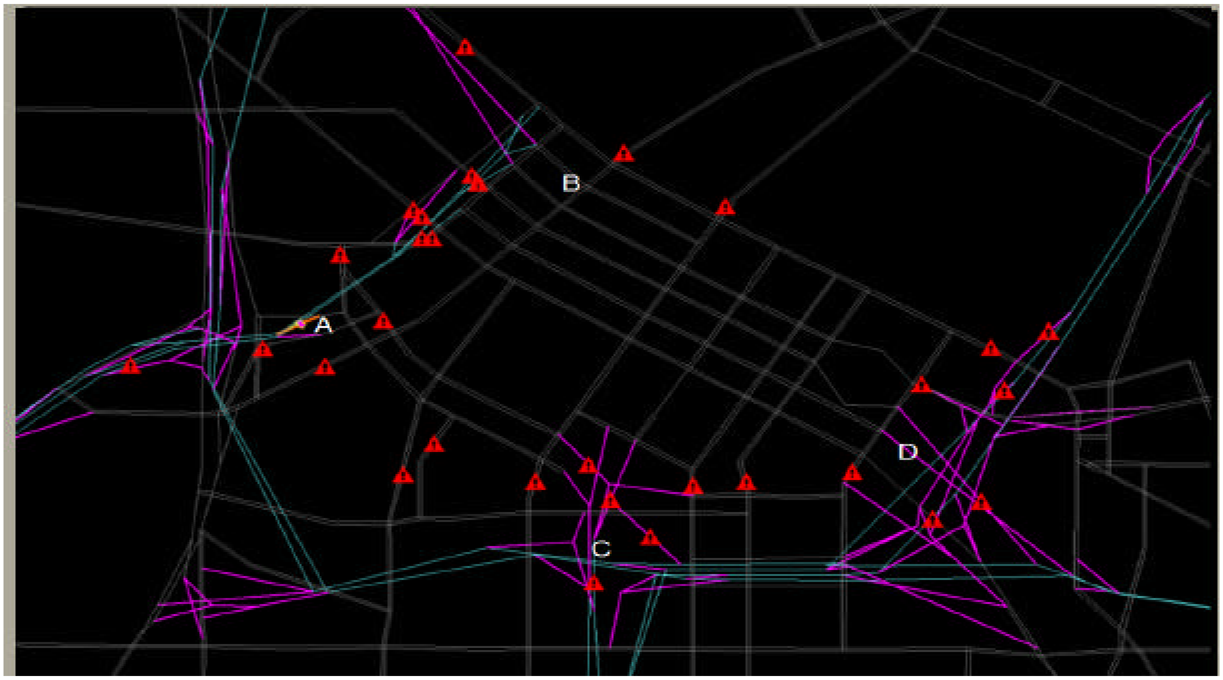

Figure 2.3.2 Location of the Arterial links blocked in #1
(A-D: Evacuation time estimation links)

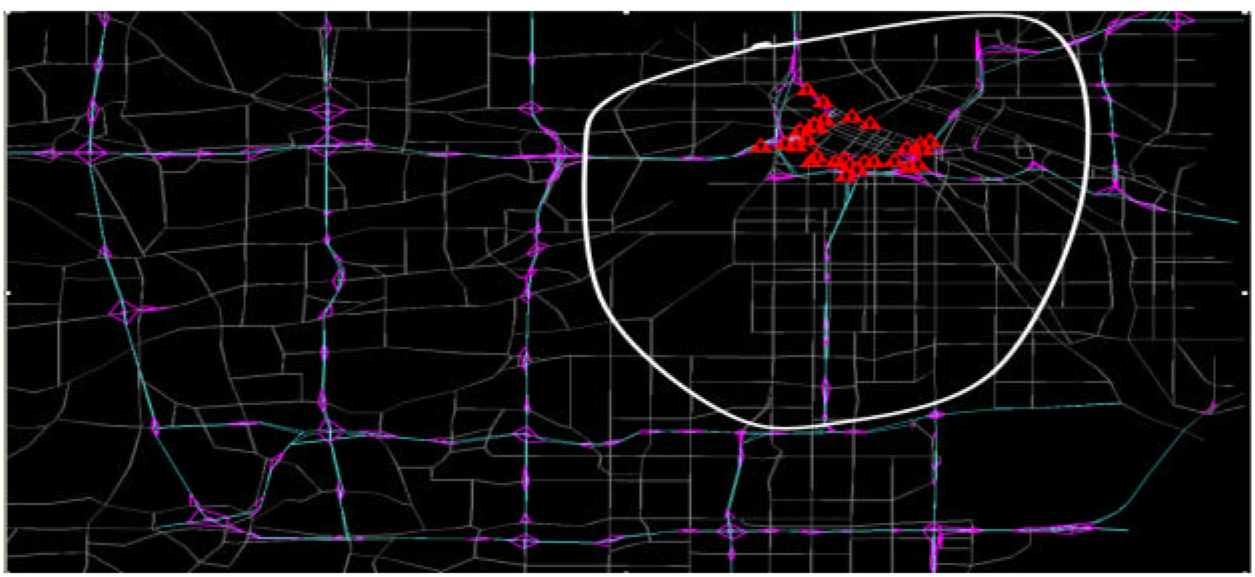

Figure 2.3.3 Location of the freeways whose inbound links are blocked in #2

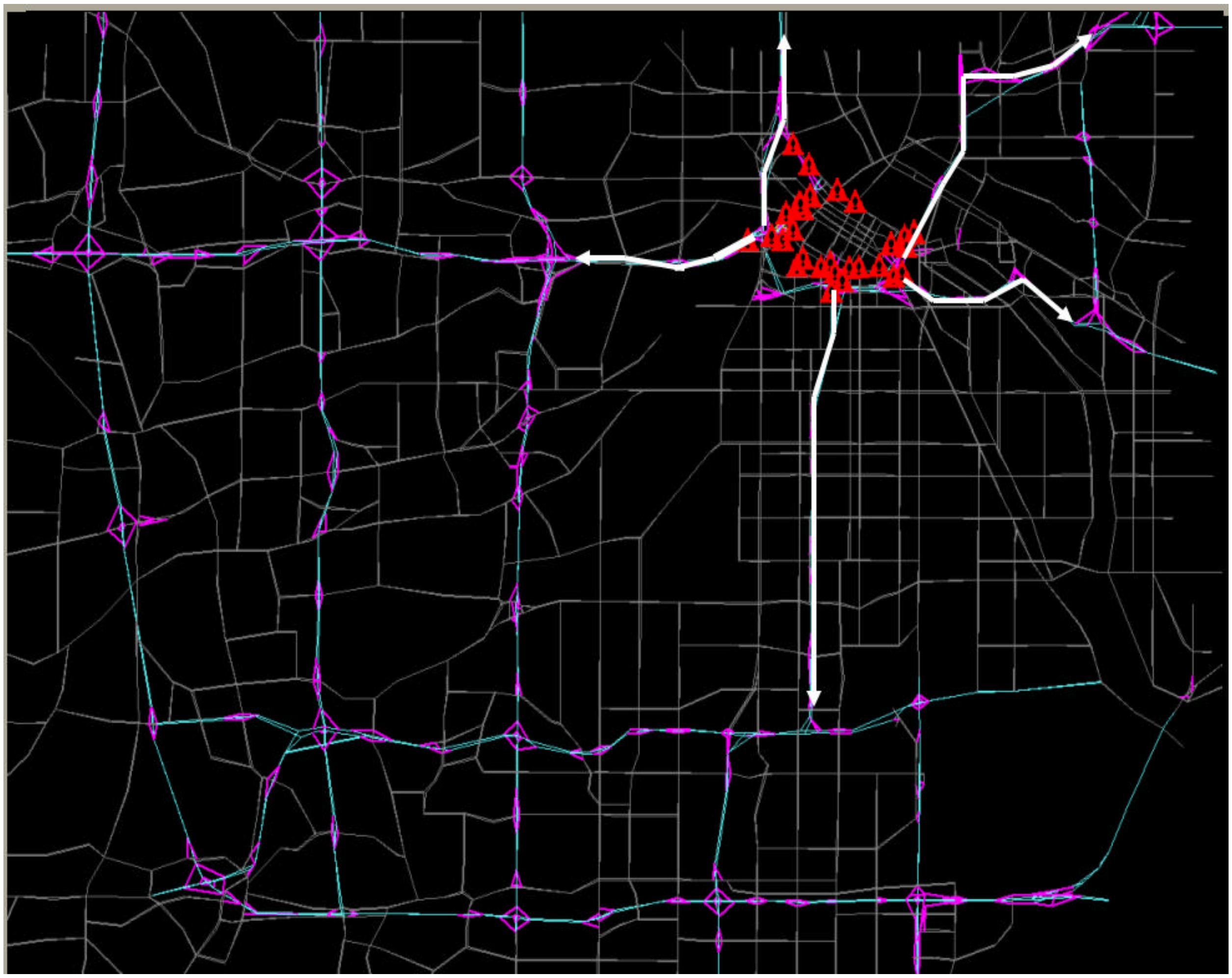

Figure 2.3.4 Location of the freeways whose directions are changed during evacuation in #3

operate with their full number of lanes, while the original inbound links have the incidents that completely block the entire links until the end of the simulation period. It can be pointed out that the freeway sections used in the contra-flow operations currently have concrete-median-barriers and the opposing flows make little impact on the directional capacity on those freeways. Therefore, in this study, no changes on freeway lane capacity because of the directional changes in traffic flows were assumed.

The above treatments of the network changes modeled in this simulation assume that all the network changes can happen in a very short time when the evacuation starts. It is also assumed that all the drivers in the network are fully aware of the network configuration changes and can adjust their routes accordingly during the simulation. In addition, those downtown zones to be evacuated would not have any incoming demand from the time evacuation starts. While these assumptions may not be realistic under real emergency situations, the results from this analysis can provide the insight on the operational goal for the emergency evacuation.

2.4 Simulation and Evaluation of Alternative Evacuation Strategies with Dynasmart-P

The alternative network configurations developed in the previous section were simulated with different demand sets using the personal computer that has a 1 GB of RAM with a 2 GHz-Pentium 4 processor. Both #1 and #2 took approximately 2 hour-execution time, while the #3 case took 19 hours to complete a run. In this simulation, a common random seed was used for a fair comparison of different options. To estimate evacuation time from the downtown area, a set of four outbound links located at the boundary of the evacuation area were selected and the traffic flow variations of those links were collected from the Dynasmart-P output files. Figure 2.3.2 also shows the locations of those four links, i.e., A-D, whose traffic performance data were stored.

Figure 2.4.1 through 2.4.4 show the traffic flow rate variations through time at those four links with the evacuation demand set #1, i.e., a total of 32748 vehicle trips. As indicated before, the duration of the total simulation period is 180 minutes and the evacuation starts at 61^{st} minute in the simulation. As indicated in these figures, the flow clearance time after the evacuation starts ranges from 21 to 27 minutes at those four links and it's interesting to see that three alternative network configurations did not make much difference in terms of evacuating downtown traffic. It can be noted that all three alternatives have same network configurations for the downtown area, e.g., same capacities for all the entrance ramps, and only external freeway configurations were changed. To evaluate the effects of the ramp capacity increase on the evacuation time, the capacities of two key entrance ramps from the downtown area to outbound freeways were increased. Figure 2.4.5 shows the locations of those two entrance ramps, i.e., for 394 westbound and 35W southbound. In the second set of simulation, the number of these two ramps was increased by one and the same demand set, i.e., #1, was applied for each network configuration. Figures 2.4.6 to 2.4.9 show the flow variations of the four links when only the inbound arterial links were blocked. As indicated in these figures the flow clearance time at these four links are not significantly different between with and without increase of the ramp capacities, while it can be clearly seen that with the increased ramp capacity, the flows at those links during evacuation are lower than the current case. The similar patterns were also found with the cases where the incoming freeway links were blocked, i.e., #2 network configuration, as shown in Figures 2.4.10 and 2.4.11. The most significant difference in evacuation time with the ramp capacity increase was observed with the

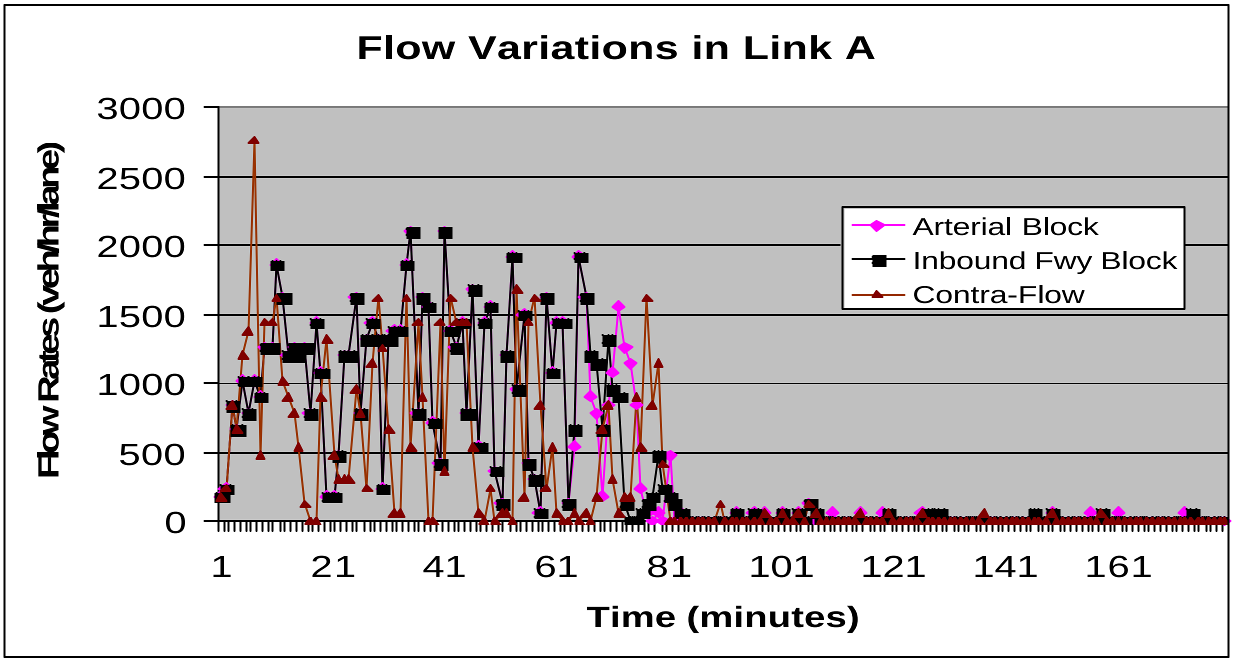

Figure 2.4.1 Flow variations through time at Link A for different network configurations

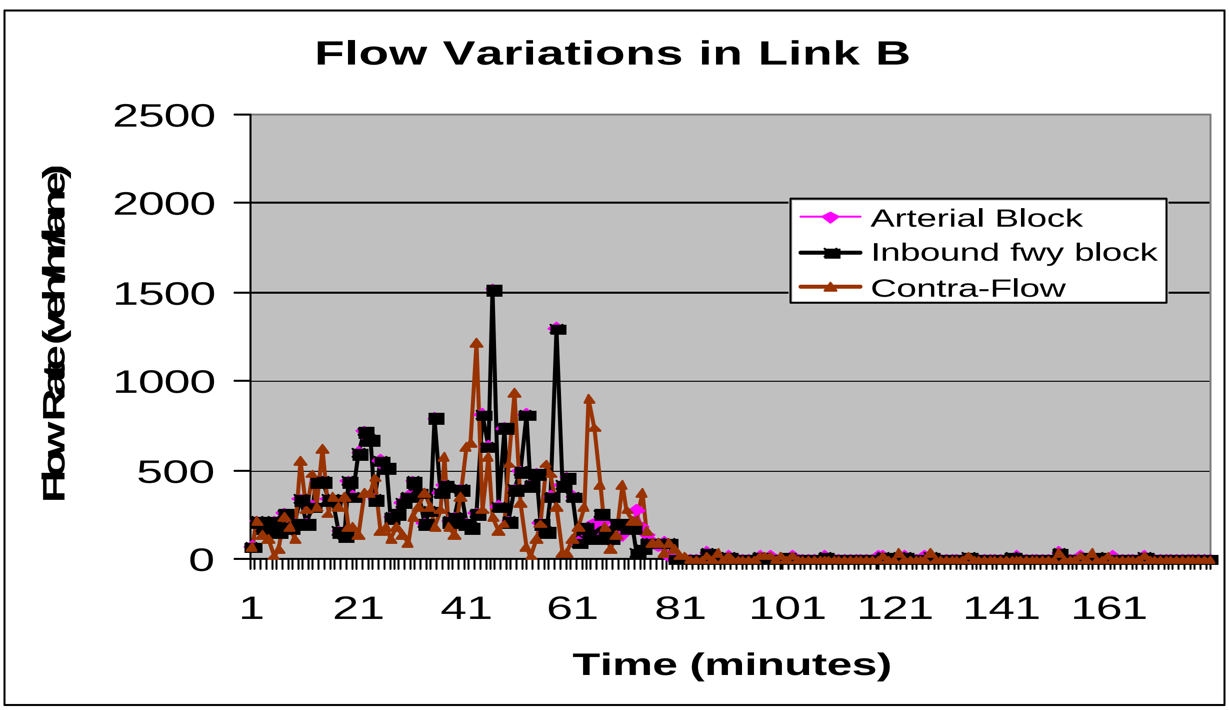

Figure 2.4.2 Flow variations through time at Link B for different network configurations

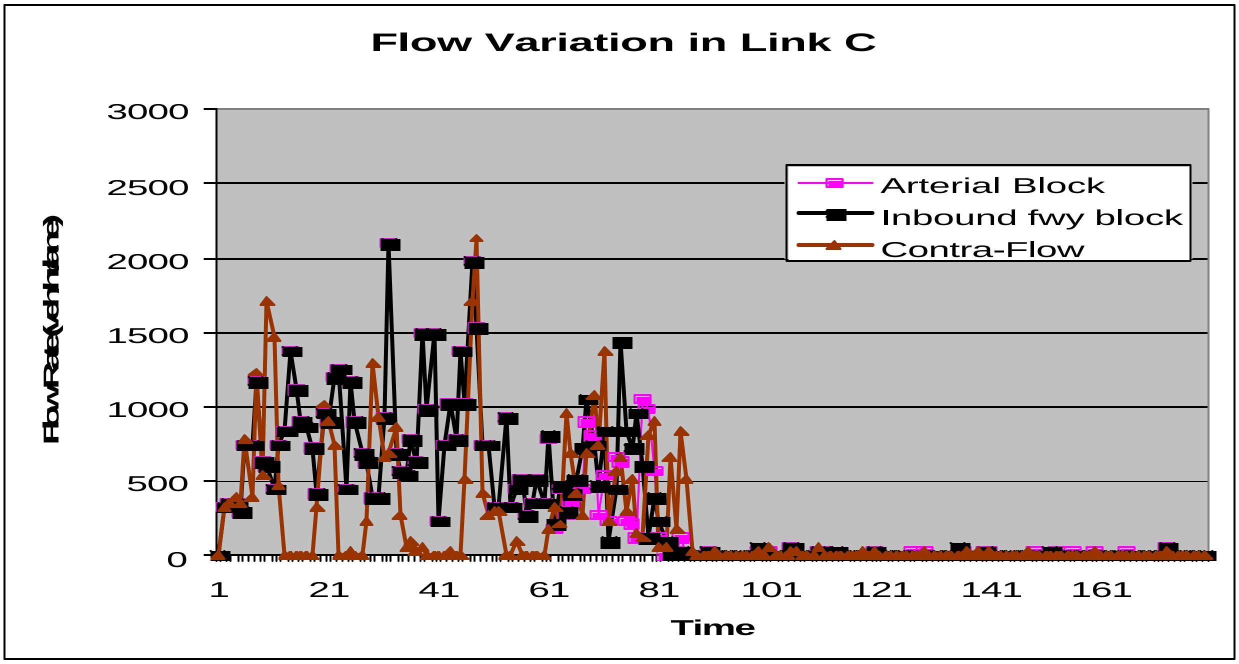

Figure 2.4.3 Flow variations through time at Link C for different network configurations

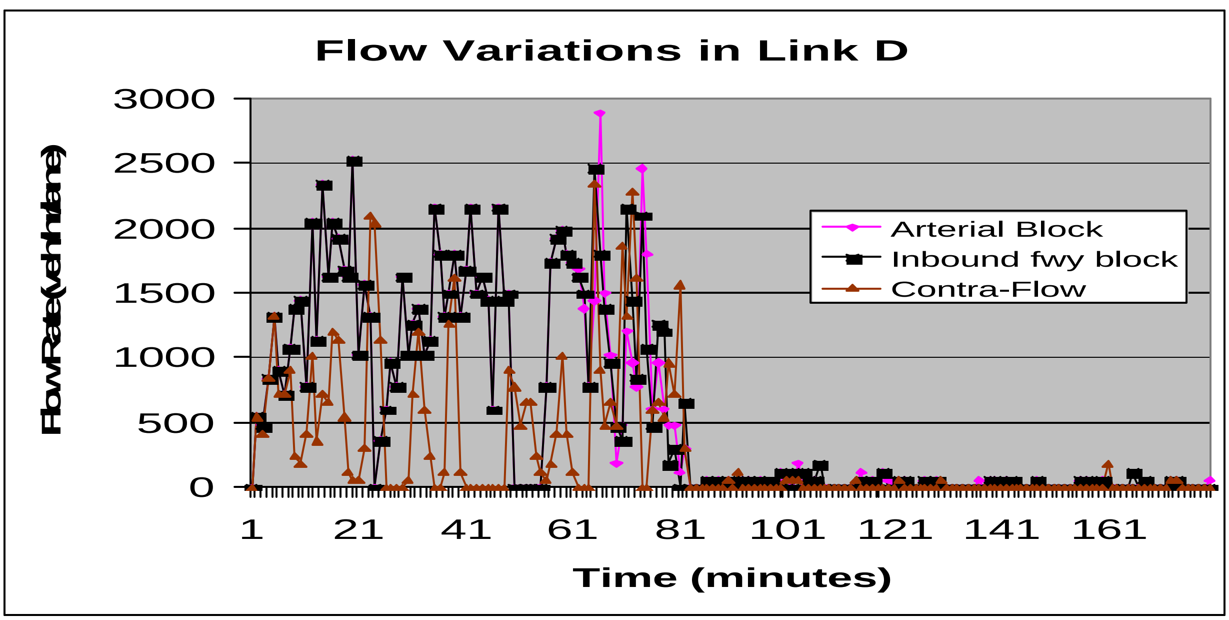

Figure 2.4.4 Flow variations through time at Link D for different network configurations

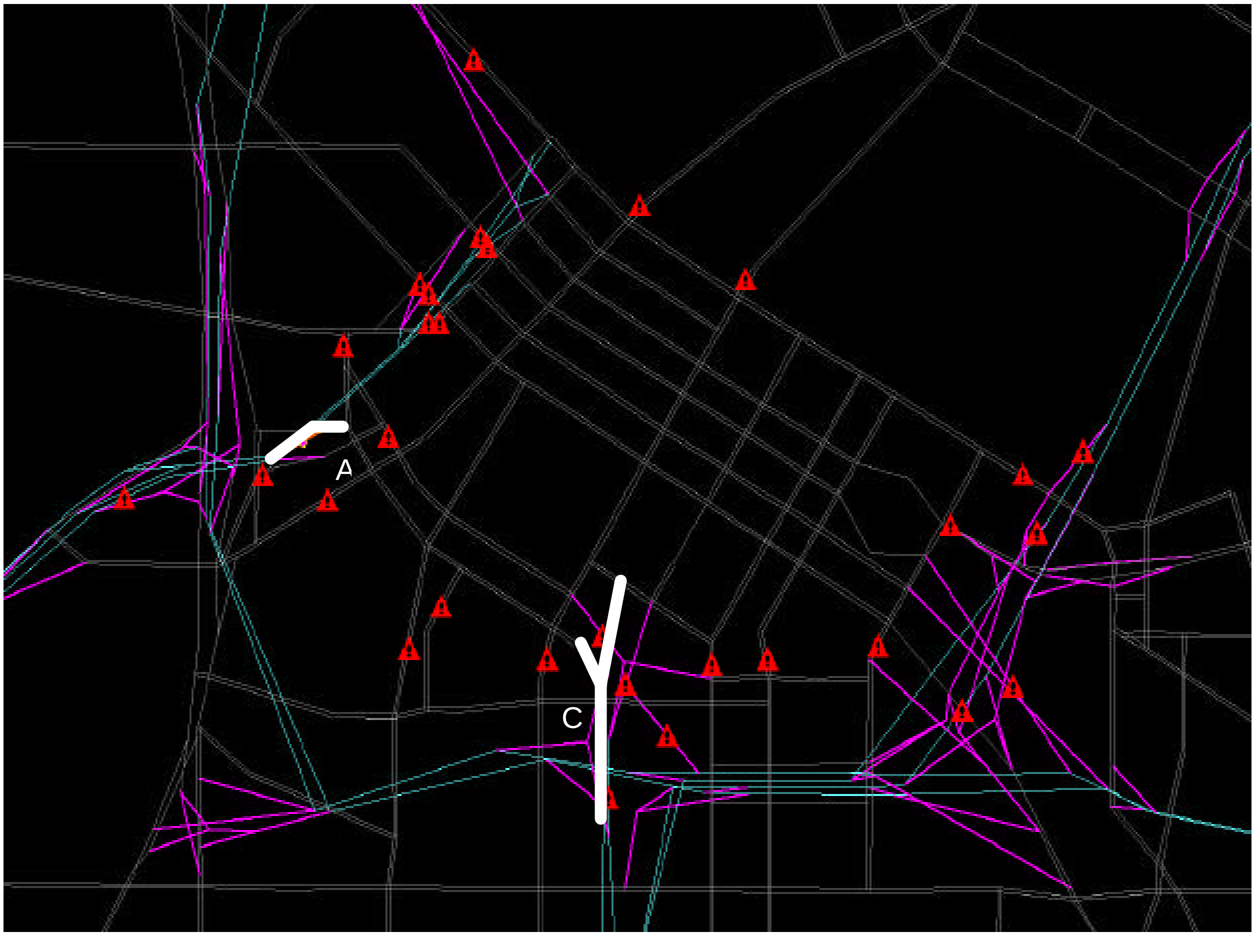

Figure 2.4.5 Location of two entrance ramps with increased number of lanes (A and C)

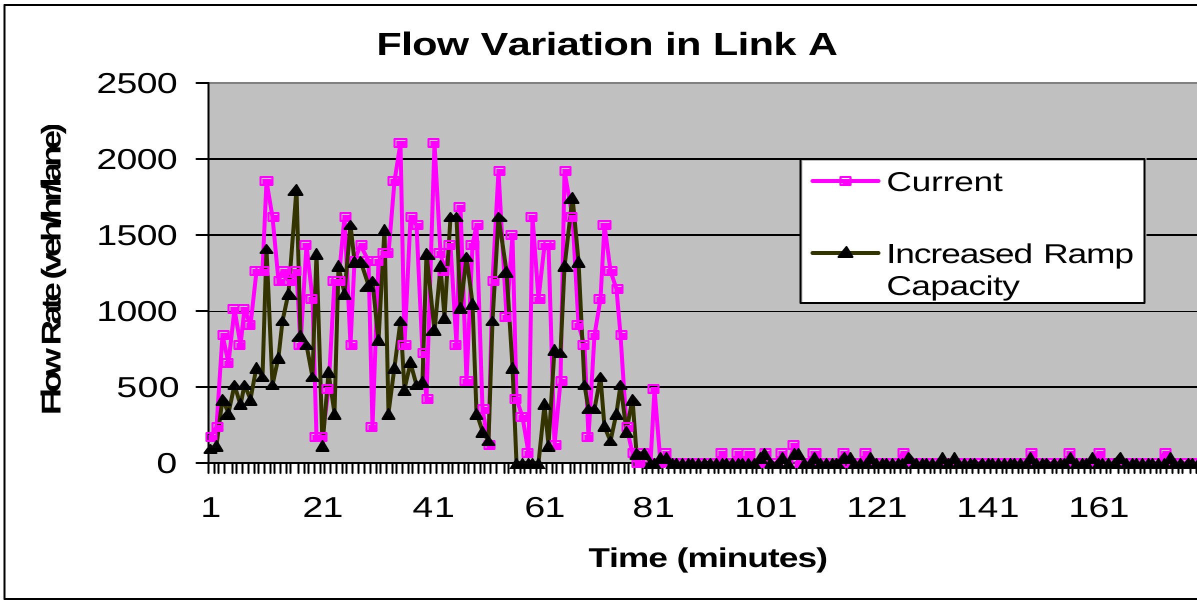

Figure 2.4.6 Flow variation in Link A with the Network Configuration #1

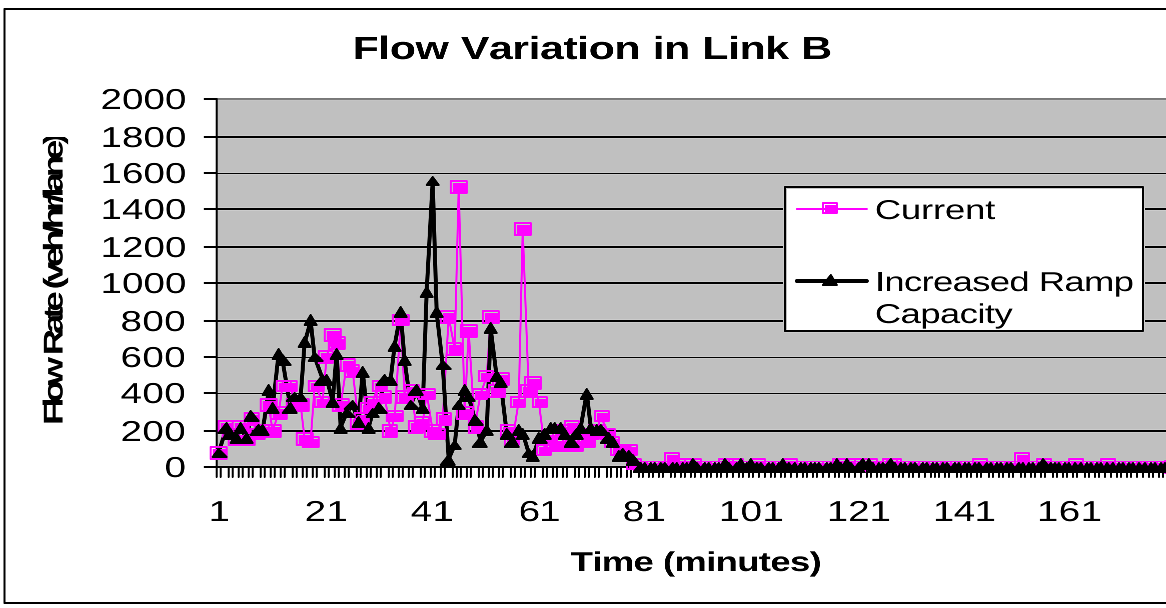

Figure 2.4.7 Flow variation in Link B with the Network Configuration #1

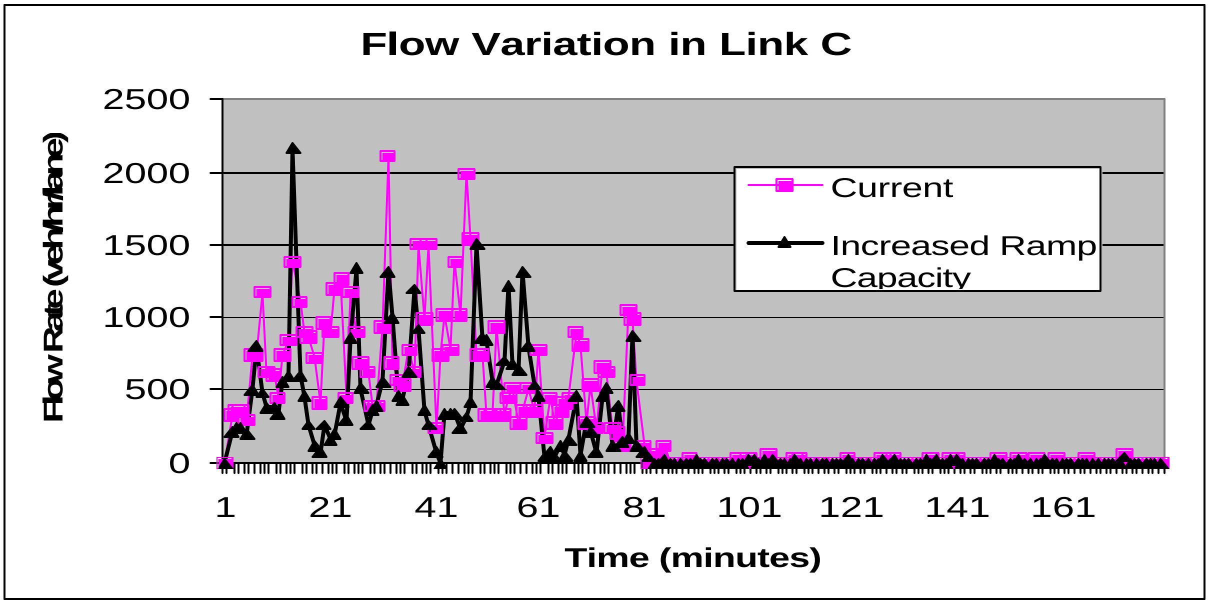

Figure 2.4.8 Flow variation in Link C with the Network Configuration #1

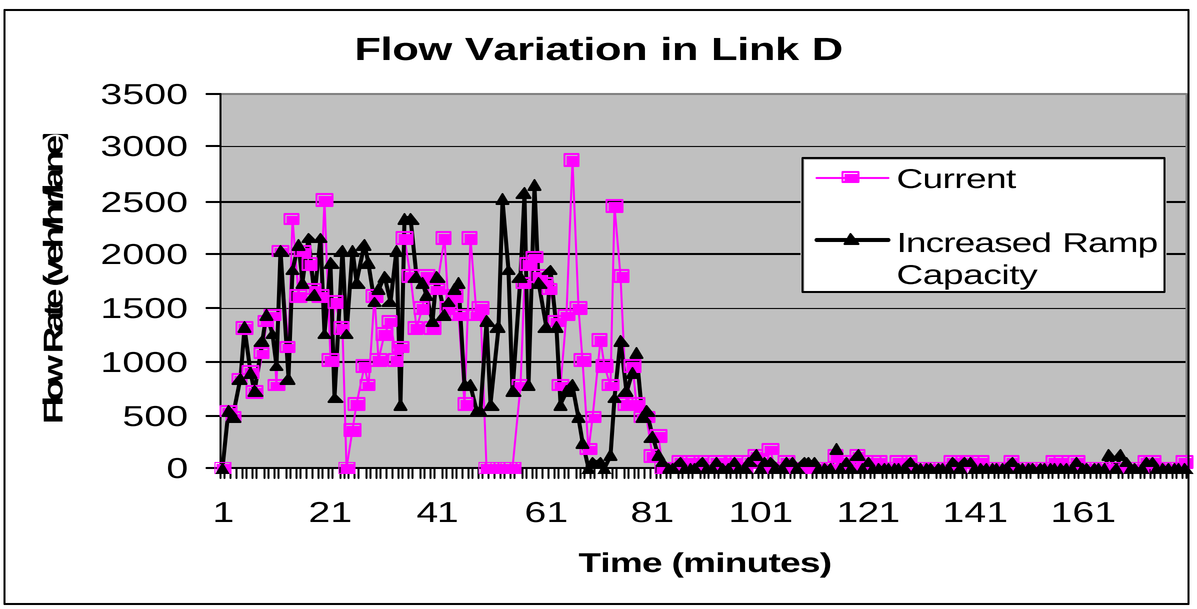

Figure 2.4.9 Flow variation in Link D with the Network Configuration #1

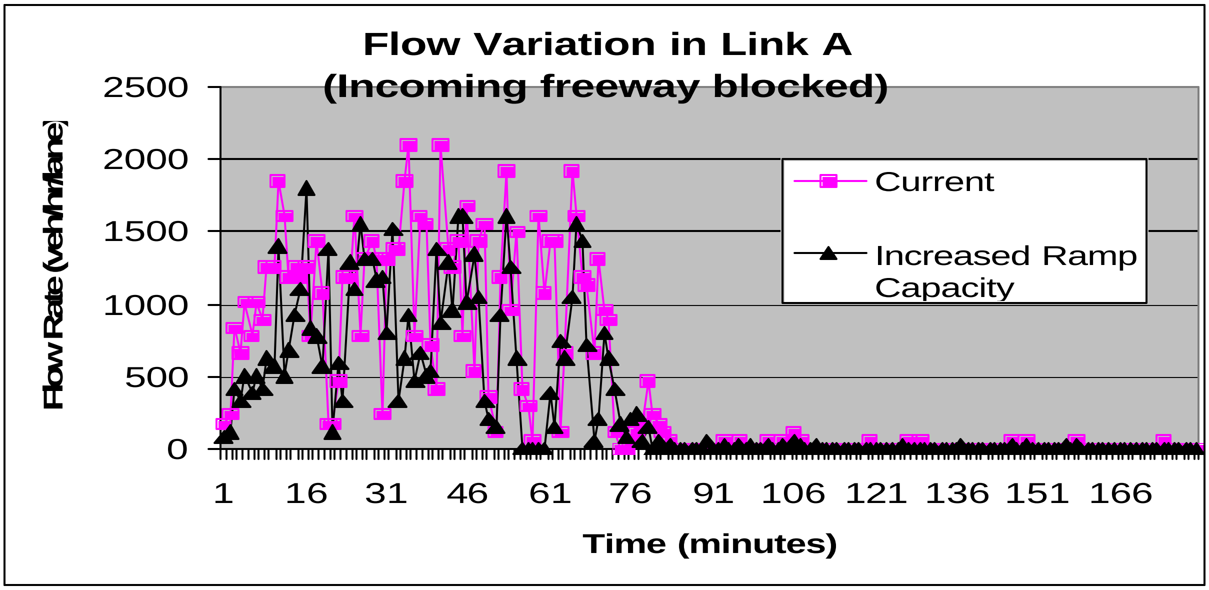

Figure 2.4.10 Flow variation in Link A with the Network Configuration #2

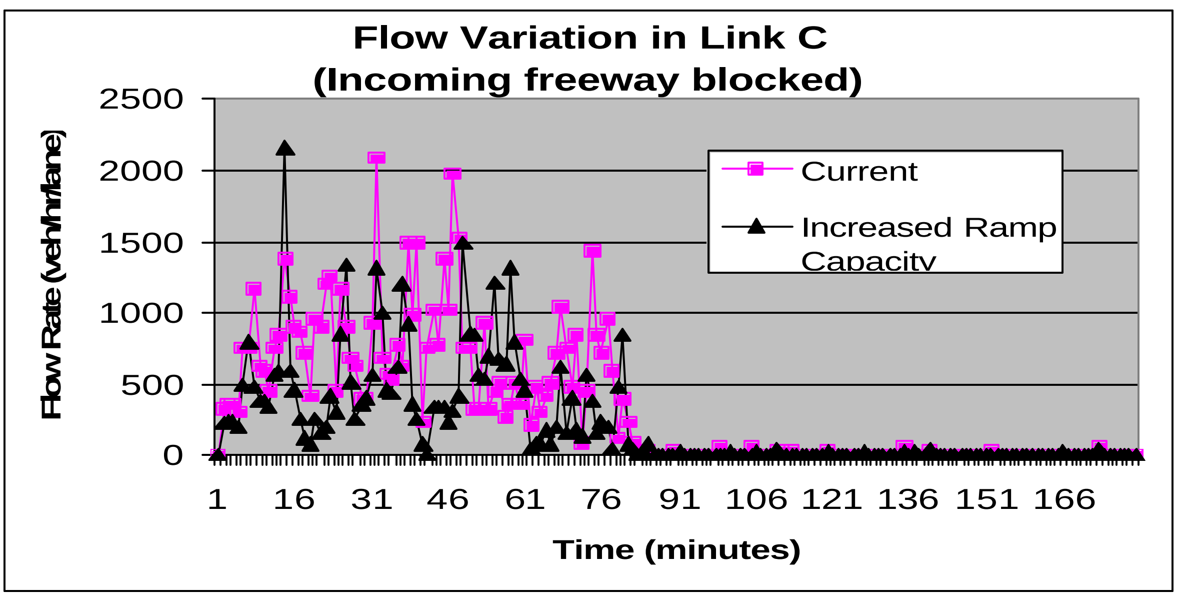

Figure 2.4.11 Flow variation in Link C with the Network Configuration #2

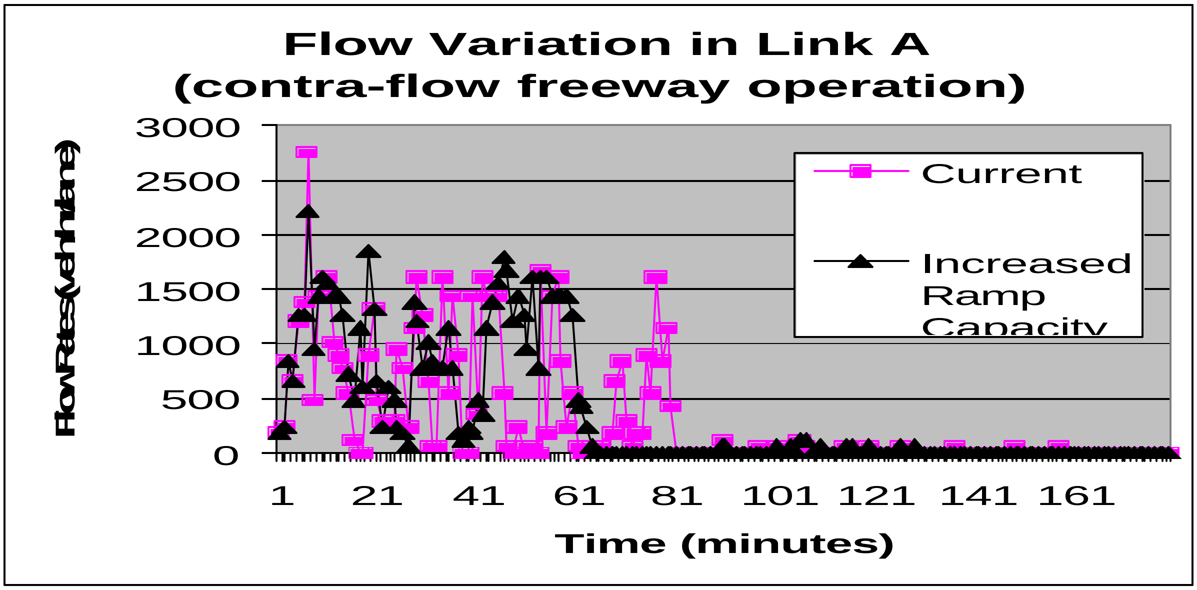

Figure 2.4.12 Flow variation in Link A with the Network Configuration #3

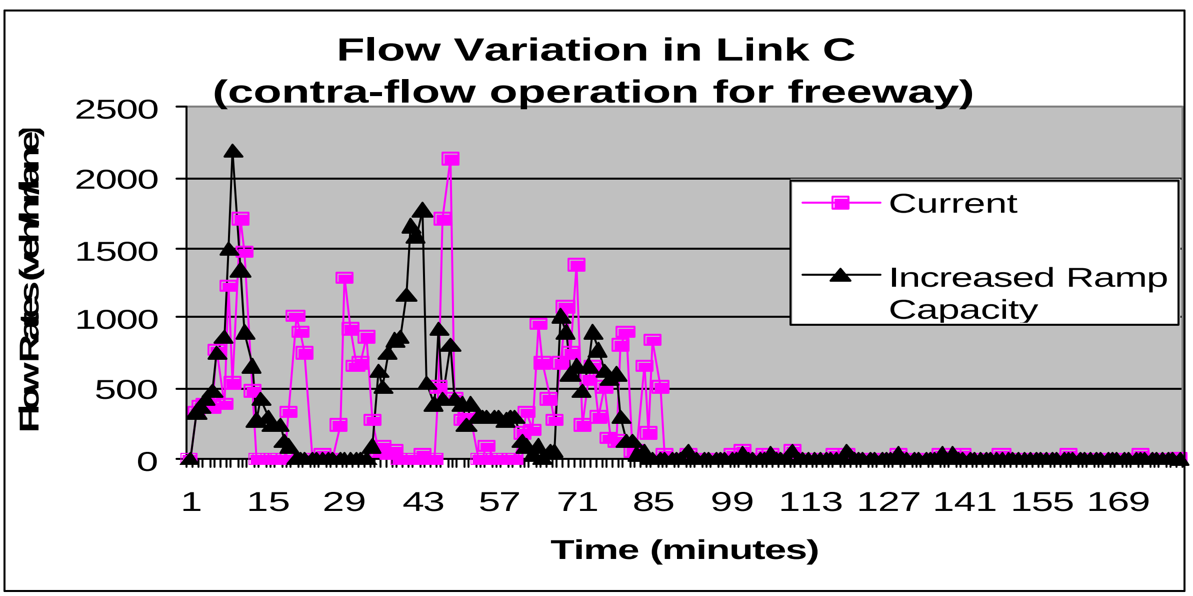

Figure 2.4.13 Flow variation in Link C with the Network Configuration #3

network configuration #3, i.e., the contra flow operation case for freeways. Figures 2.4.12 and 2.4.13 include the simulation results for the two ramp links whose capacities were increased. As shown in these figures, the evacuation times were substantially reduced, i.e., 5 to 15 minutes, with the increased ramp capacity when the inter-ring freeways were converted into outbound one-way links.

Finally the total evacuation demand from the downtown area including the Metrodome was increased from 32428 to 40898 vehicle trips, which indicates almost 100% increase of the non-Metrodome evacuation demand. First, the network configuration #1, i.e., blocking only the inbound arterial links to downtown, was simulated with the increased evacuation demand. Figures 2.4.14 to 2.4.17 show the comparison of the flow variations at each link for two evacuation demand cases. As shown in these figures, the flow clearance times at those four links are increased from 21-27 minutes to 56-75 minutes. Figures 2.4.18 and 2.4.19 show the simulation results with the network configuration #2, blocking incoming freeway links in addition to the inbound arterial links, which indicate similar results as the previous case.

The analysis of the simulation results performed in this study shows that when the downtown network configuration is not changed, e.g., without ramp capacity increase, the changes in the external freeway configurations do not make significant differences in terms of the evacuation time from the downtown area. This suggests that, when the traffic at the outbound freeway links are not congested at the time when evacuation starts, and the incoming demand to the downtown zones can be controlled continuously during the evacuation period, the network configuration #1, which blocks only the inbound arterial links to the downtown area, would be as effective as any other alternatives tried in this study. However, when the access capacity to the freeway network is increased, it is shown that the contra-flow operations with the outbound freeway links would substantially reduce the flow clearance time from the downtown area. Future studies should address the effects of different compositions of the driver population on the evacuation time in terms of their familiarity with the network, route preference and availability of the real-time information

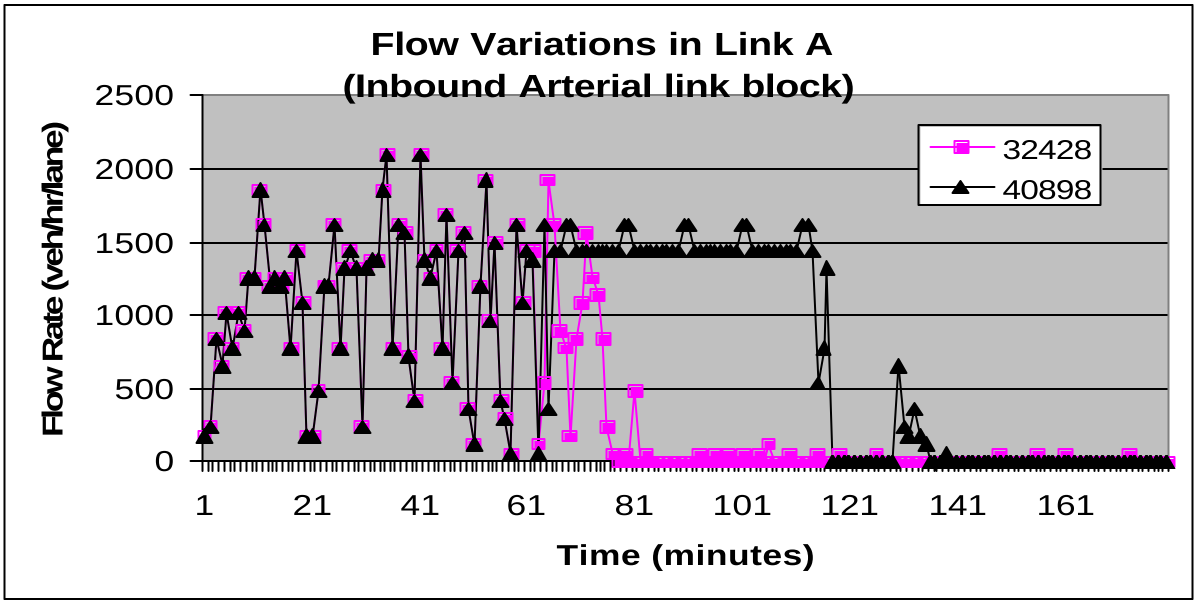

Figure 2.4.14 Flow comparison with different evacuation demand
(Link A with the Network Configuration #1)

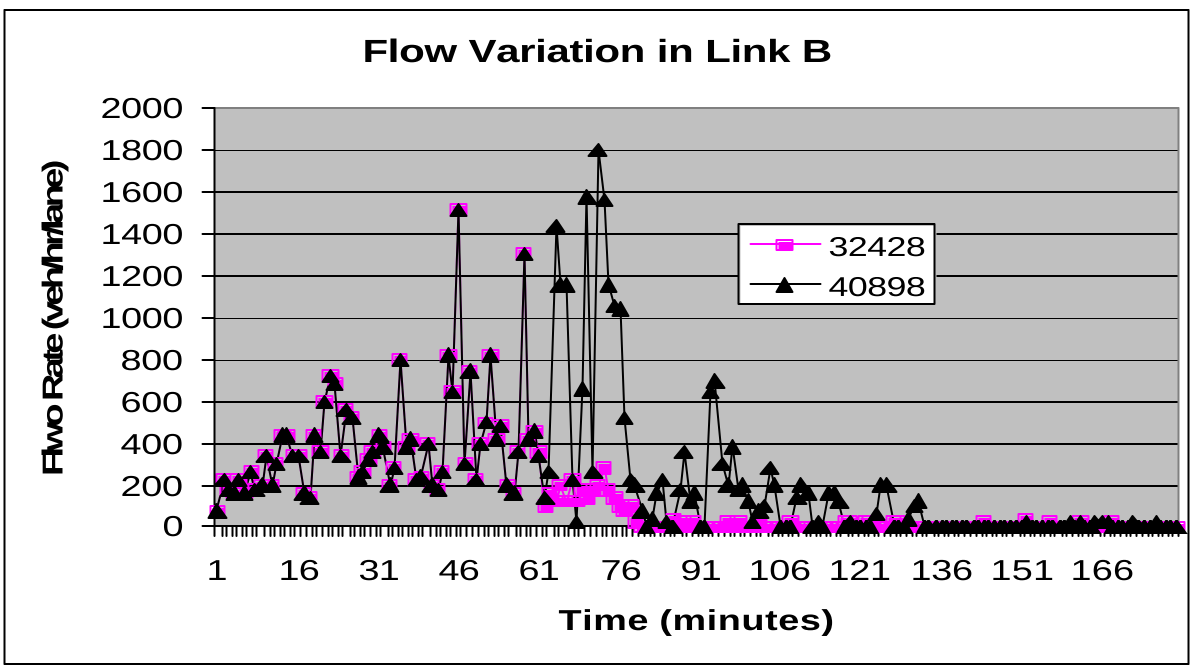

Figure 2.4.15 Flow comparison with different evacuation demand
(Link B with the Network Configuration #1)

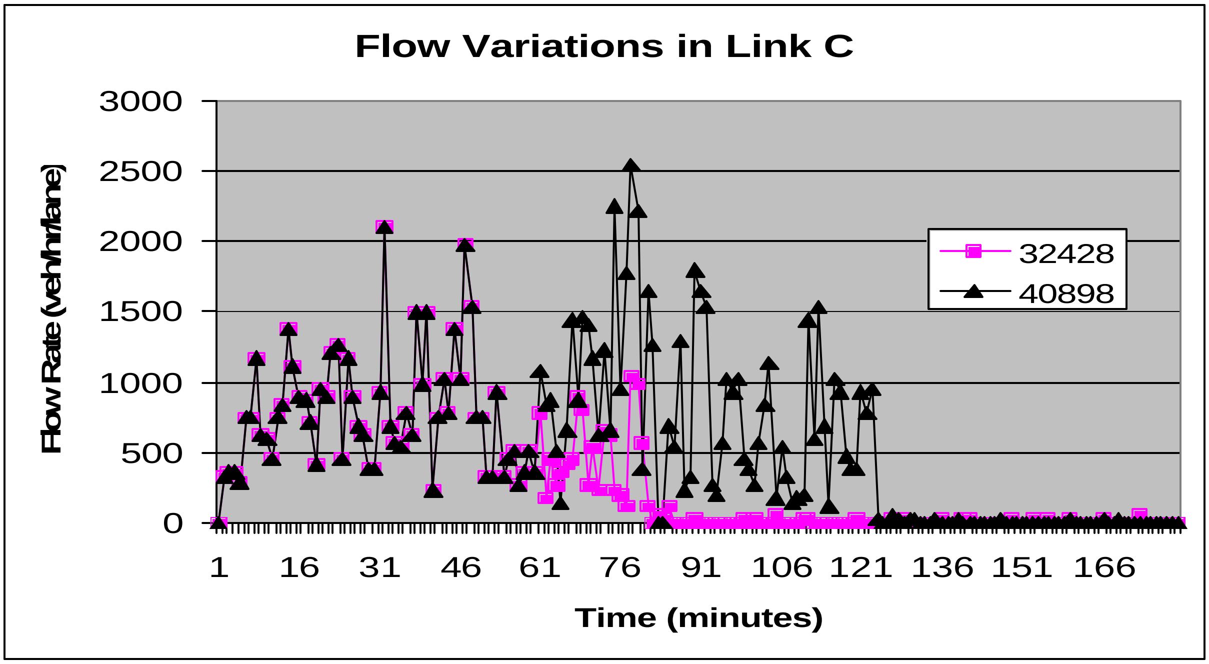

Figure 2.4.16 Flow comparison with different evacuation demand
(Link C with the Network Configuration #1)

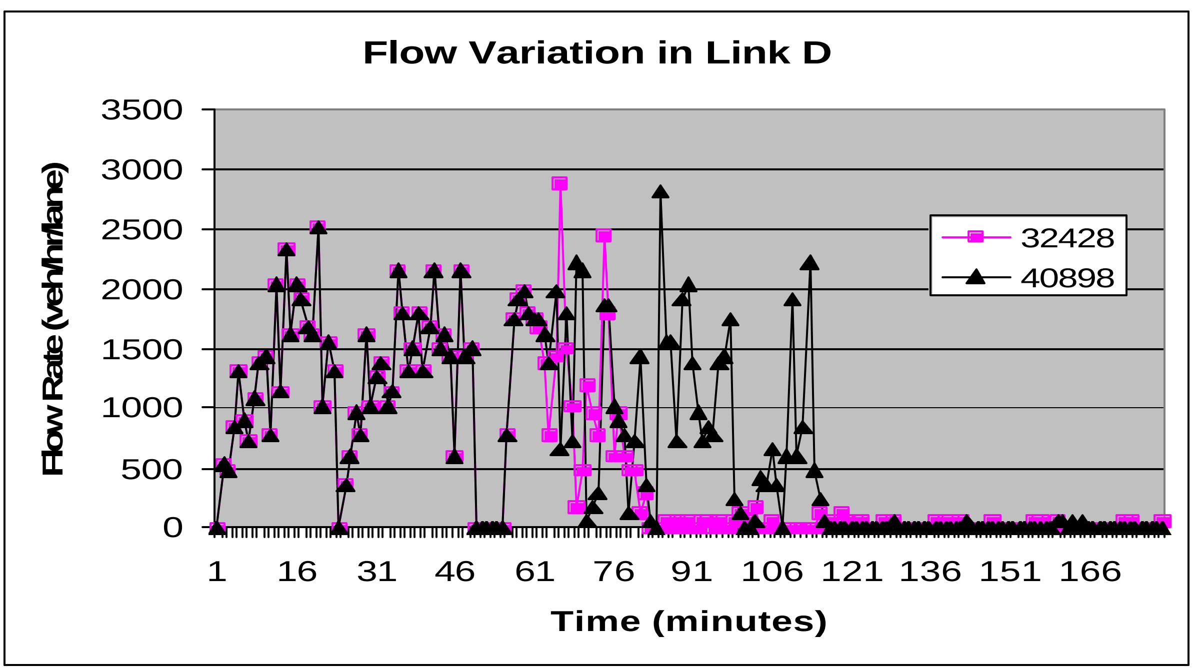

Figure 2.4.17 Flow comparison with different evacuation demand
(Link D with the Network Configuration #1)

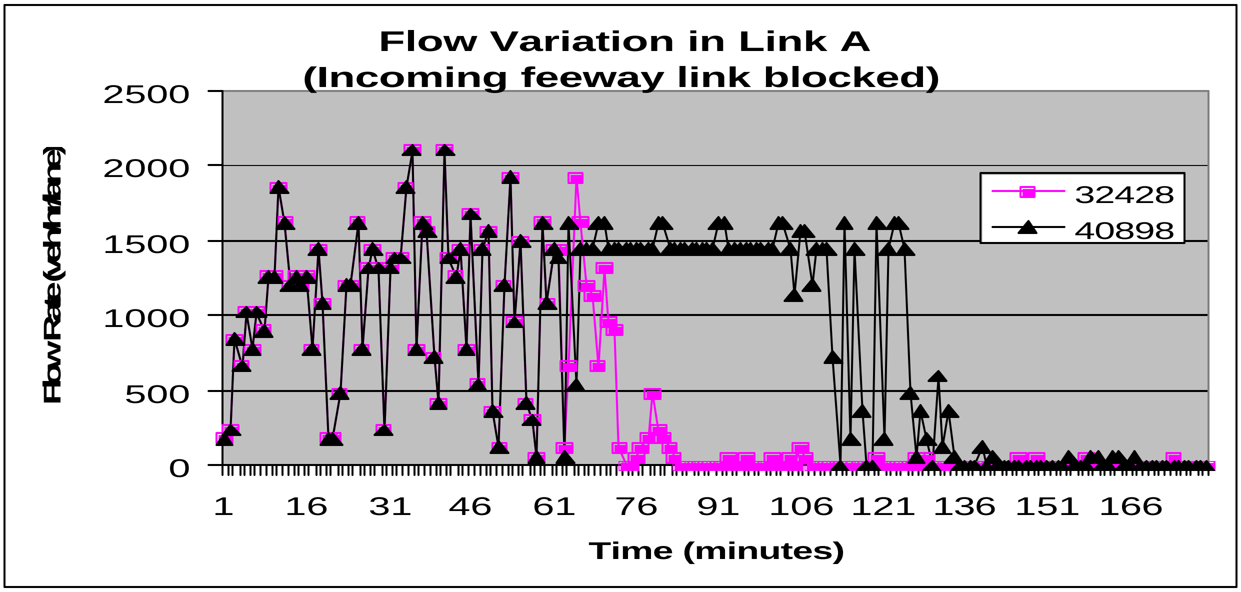

Figure 2.4.18 Flow comparison with different evacuation demand
(Link A with the Network Configuration #2)

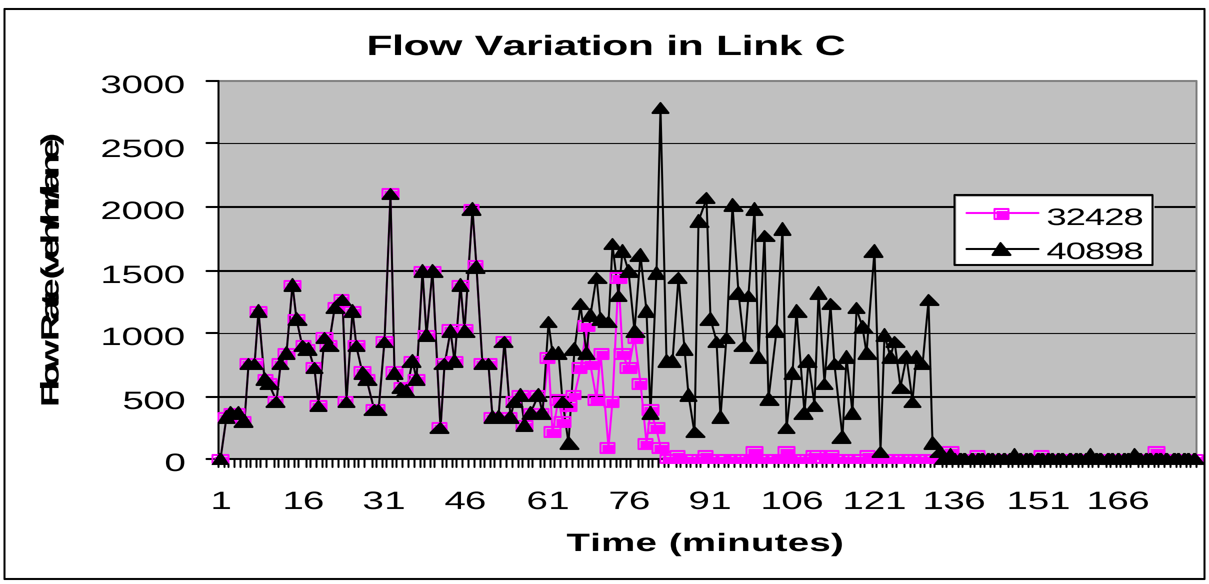

Figure 2.4.19 Flow comparison with different evacuation demand
(Link C with the Network Configuration #2)

3. DEVELOPMENT OF A REAL-TIME STRATEGY FOR FREEWAY TRAVEL-TIME ESTIMATION

3.1 Review and Selection of Candidate Travel-Time Algorithms for Minnesota Freeway Network

There are four metro areas in US currently providing freeway travel-time information in real time. Those cities include Atlanta, San Antonio, Milwaukee and Chicago. In this research, the main features of the travel-time algorithms being implemented at those cities were collected through literature search and telephone interviews with the system managers at each city. Based on the review, a candidate algorithm was determined for further evaluation with the Minnesota freeway network. The rest of this section summarizes the major features of those algorithms reviewed in this study.

Chicago, Illinois

The Illinois Department of Transportation adopts a 'snap-shot' based travel-time approach, where a travel-time route is divided into a set of 'links' and the travel time of a given route is determined as the sum of the link travel-times estimated with the current speed level at each link. A link is defined as the roadway section between the midpoints of two adjacent detector stations, therefore, each link contains one loop station. Figure 3.1.1 shows the configurations of a link used for travel time calculation by the cities reviewed in this study. The speed data of a link is derived from the volume and occupancy measurements at the loop detectors every 20 seconds. If two or more detectors consecutively located within a route are not working properly, then the travel time of that route is not displayed. Travel times are displayed with variable message signs (VMSs) during peak hours only and updated every one to five minutes, while the web-based travel time information is updated every three minutes. The common format of the VMS display is "X min to DESTINATION." If there is a major incident during peak hours, the incident will be displayed (Lee, 2004).

San Antonio, Texas

The San Antonio travel-time system, started in November, 1999, displays travel times to major intersections or major interchanges with variable message signs. The length of the travel-time routes range from 5 to 10 miles. A traffic sensor, a loop or video detector, is placed approximately every half a mile and provides speed measurements every 20 seconds. A link is defined as the roadway segment bounded by upstream and downstream detectors as shown in Figure 3.1.1. The travel time algorithm takes the lower value of the upstream and downstream speed measurement as the speed of a link. The travel time of each link is then calculated with the current speed measurement and the sum of all the link travel times for a given route is displayed as the estimated route travel time at that time. The travel time display is updated every 1 minute automatically.

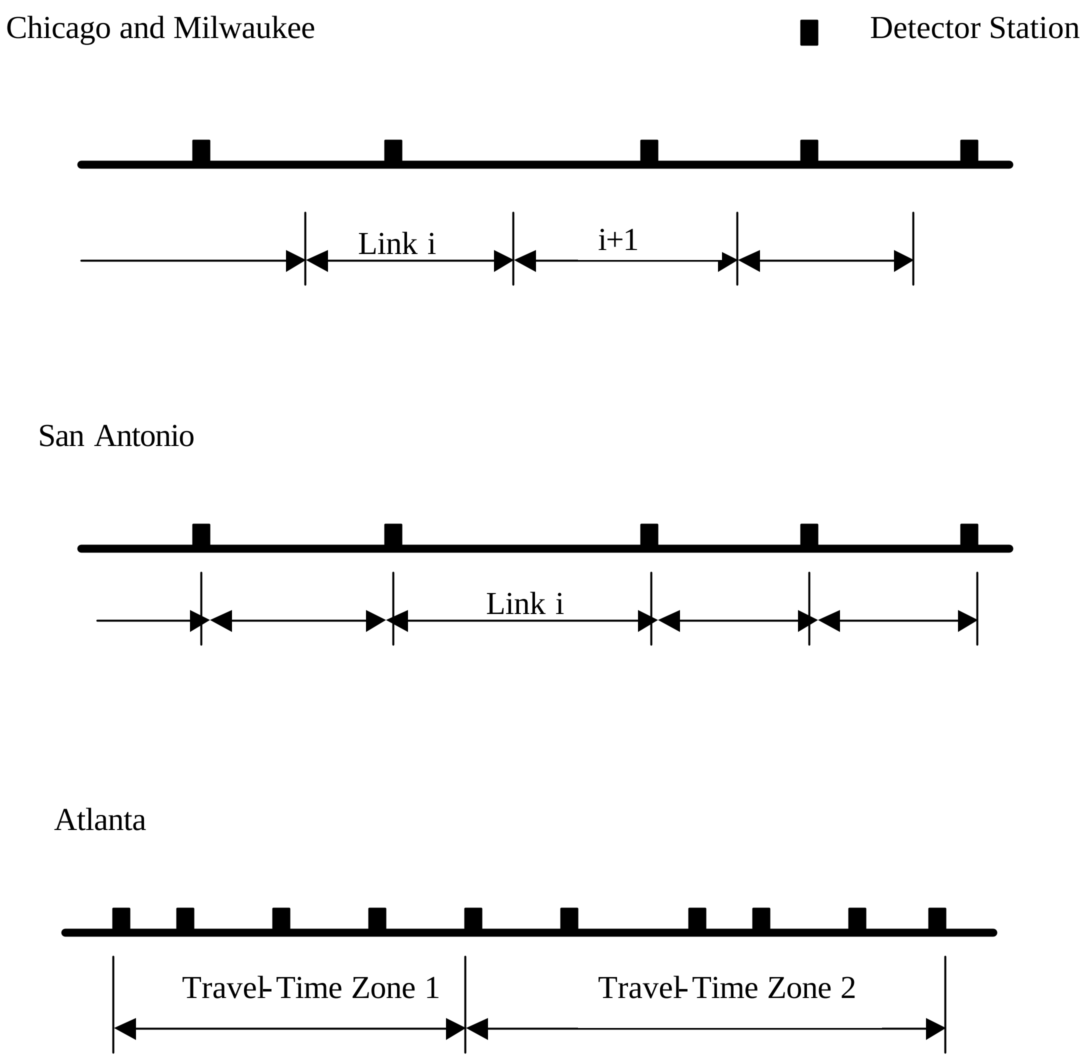

Figure 3.1.1 Link configurations for travel-time calculation at different systems

The travel times in San Antonio are displayed from 6:00 am to 10:00 pm seven days a week on freeway mainlines. In particular, to address the lane-by-lane variability of travel times and speed variations among drivers, the travel times are displayed as a range of times. For example, if the time is less than 5 minute the VMS will display "under 5 minutes." If the travel time is between 5 and 20 minutes a two minute range will be shown. When the travel time is between 20 and 30 minutes a range of three minutes is displayed. If the travel time is over 30 minutes than "over 30 minutes" is displayed, but this situation usually results from an incident. In such a case, incident information is displayed instead of travel times (Texas DOT, 2004).

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Milwaukee, Wisconsin

The current travel-time system in Milwaukee Wisconsin displays travel times every 1 minute for 72 predefined routes using a total of 36 VMSs. Each VMS shows the travel times for two destinations from the VMS location. Approximately 90% of the current detection system in Milwaukee consists of double loop detectors which measure speed directly every 20 seconds. The system automatically checks for malfunction detectors, and to be able to calculate a travel-time for a route, at least 70% of the detectors in that route need to work. The Milwaukee system also adopts the 'snap-shot-speed' based travel time approach, i.e., the travel time for a given route is the sum of the travel times of the links belong to that route. A link is defined same as the Chicago system, i.e., the roadway segment between two midpoints of adjacent detector stations as shown in Figure 3.1.1 (Shell, 2004).

Atlanta, Georgia

In the Atlanta system, all the freeways are divided into 'travel-time zones' depending on the traffic flow patterns. Each zone consists of several detectors, all of which are video detection systems collecting speed data every 20 seconds. Every VMS used for travel time display has a pre-assigned route consisting of multiple travel-time zones with a look-up table, which contains pre-calculated travel times for the given route depending on the average speed of each travel-time zone. Therefore, the travel-time for a route is 'selected' from the loop-up table, calibrated off-line with field observations, using the average speed measurements for the travel-time zones within the given route. The travel-time display is updated every 1 minute (Demidovich, 2003).

Selection of Candidate Travel-Time Algorithm

As reviewed above, all the operational algorithms for travel-time calculation in real time adopt either the 'snap-shot-speed-based' algorithm or selects a travel time from a look-up table using only current measurements without explicitly employing prediction or historical data. While several researchers presented prediction-based methods that use both current and historical data, the accuracy of those methods has not been proven to be applicable on a daily basis. Further, the effectiveness of those historical-data based methods can be significantly affected by the types of 'historical' data used for travel time determination and the definition of 'historical' data has not been clearly established. In this research, a modified snap-shot-based algorithm is proposed for estimating travel times in real time for pre-defined routes. Figure 3.1.2 shows the link configuration of the candidate algorithm which divides a segment between two detector stations into three equal-length links whose speed values are determined by those boundary detector stations as follows:

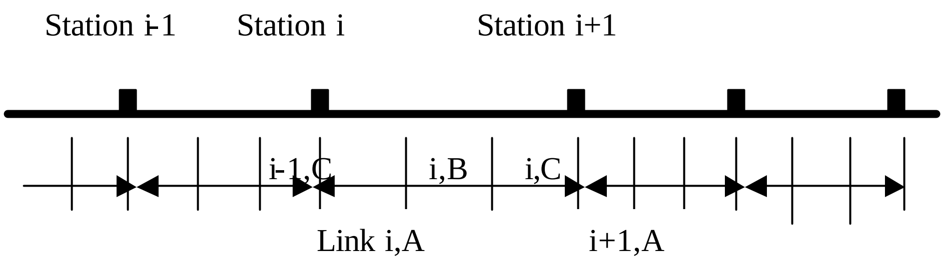

Figure 3.1.2 Link configuration of the candidate algorithm

Speed at time t for Link i-1,C and Link i,A = Speed at time t from Detector Station i
Speed at time t for Link i,C and Link i+1,A = Speed at time t from Detector Station i+1
Speed at time t for Link i,B = average speed of Link i,A and i,C

The above methodology is to effectively reflect the speed variations within two detector stations on a freeway segment. Further, when a detector station is malfunctioning, a new set of links can be configured in real time using available upstream and downstream detector stations.

3.2 Data Collection from the Minnesota Freeway Network for Travel Time Estimation and Testing

The data needed for travel-time estimation includes the location of each detector station, length between two consecutive stations, sample travel-time data for selected routes and the parameters to calculate speed values from loop-based volume/occupancy measurements. In this research, the digital map data for the metro freeway network was first collected in cooperation with the GIS group at the Minnesota Department of Transportation (Mn/DOT). Next all the GPS coordinate data for each detector station, collected by the engineers at the Regional Traffic Management Center (RTMC), Mn/DOT, were coded into the ArcView freeway map. Finally, the distance between two detector stations on each freeway corridor was measured on the digital map using the network analysis function of ArcView. Figure 3.2.1 shows the ArcView freeway network including all the detector stations currently in operation. In this study, the distance data between two stations and pseudo mile-point of each station to be used for travel-time determination were estimated using the network analysis function of the ArvView.

The next set of the real data includes the field travel time measurements collected with a probe vehicle equipped with the GPS device, which downloads the coordinates of the probe vehicle every 5 seconds as it travels along a pre-determined route. The downloaded GPS coordinates were processed and coded into the ArcView freeway map for estimating travel times between detector stations. Figure 3.2.2 shows one set of the GPS coordinates depicting the trajectory of the probe vehicle that traveled the 35W freeway corridor for this study. A total of 33 probe-vehicle runs were made from October 2003 until January 2004 to collect travel times from the selected portion of the major freeway corridors in the metro network including 77NB, 169NB/SB, 35W NB/SB, 394 EB/WB, 94 EB/WB and 494 EB/WB. Once the GPS coordinates of the vehicle trajectory resulted from each travel-time run were coded into the ArcView map, the travel time between specific points on each freeway was estimated by manually identifying the clock-times at which the probe vehicle crossed each detector station using the ArcView functions.

The processed travel-times for selected routes were used to test and improve the accuracy of the off-line travel-time estimation model developed by the software engineer at the RTMC. This model determines the travel times between two points, i.e., origin and destination detector stations, using the estimated speed data from loop detectors depending on the arrival time at an origin station through time. In particular, the travel times between two stations can be estimated

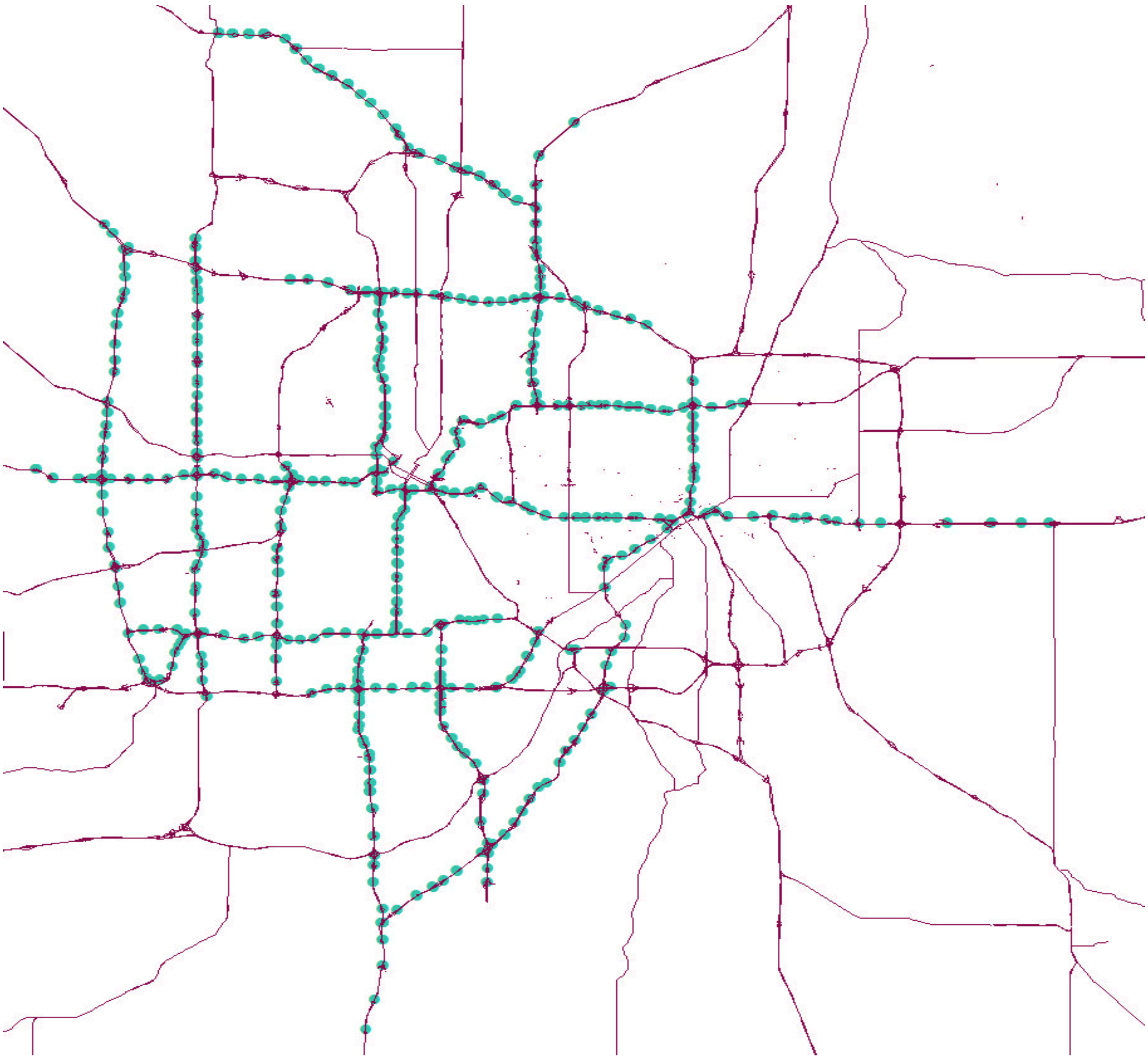

Figure 3.2.1 Location of loop detector stations on the Metro Freeway Network

Figure 3.2.2 Sample trajectory of the probe vehicle for travel-time run on 35W

every 1 minute interval in terms of the arrival time at an origin station. Figures 3.2.3- 3.2.10 show the example comparisons between the measured travel times by the probe vehicle and the estimated travel times by the off-line model. The off-line model was developed to compensate the probe-vehicle-based travel-time measurements, which can be restricted in terms of the coverage area and time periods because of the resource limitations. As shown in those figures, the off-line model can estimate the travel times between two detector stations for every 1 minute interval in terms of the arrival time, while the probe-vehicle method can provide the travel-time measurements at certain arrival times. The differences between two travel times are less than 5 % in most cases and this indicates the feasibility of using the off-line travel-time estimates as the substitutes for field measurements.

3.3 Linearity Examination and Parameter Adjustment for Spot-Speed Estimation

The general formula to estimate speed from single-loop detector data, i.e., volume and occupancy, is as follows:

Speed (mile/hr) = a (flow rate/occupancy)

The above formula indicates the linearity between traffic density and occupancy assuming a constant value of the 'detector field length', i.e., the sum of a vehicle length and electromagnetic field length of a loop detector. In this study, the above assumption was examined by collecting the spot-speed values of the vehicles crossing selected loops during off-peak and peak periods with the radar detector provided by the RTMC. The measured speed values were correlated with the volume/occupancy values collected from the loops located at the same location.

Figures 3.3.1-3.3.3 show the relationships between those two values collected from three different loops at a same location. As shown in these figures, the correlation between speed and volume/occupancy values show strong linearity at high as well as low speed ranges, while the data points tend to scatter in the low speed region. This indicates the possibility of using free-flow-speed measurements, which are relatively easy to obtain, collected at loop detector locations to approximate the detector field length values as a routine maintenance task, while the needs to check the field length values at various speed ranges on a regular basis still exist. In particular, the estimated a values for those three loops shown in those figures indicate significant variability of the field length values. The spot-speed measurements collected from this study at selected loops were used to calibrate the field length values for those detectors.

3.4 Travel-Time Route Configuration and Off-Line Testing of Candidate Algorithms for Travel Time Estimation

In this study, the northbound section of the freeway 77 was selected in consultation with the engineers at RTMC, Mn/DOT, as the test corridor for future on-line implementation of the travel time information system. Figures 3.4.1 and 3.4.2 show the initial off-line test results of the modified version of the snap-shot-speed based algorithm proposed in this chapter. The estimated travel times in those figures are the substitutes for the real travel times determined by the off-line estimation model tested in the previous section. As indicated in these figures, the snap-shot-based estimation algorithm, which determines the travel time of a route with the speed values measured at the current time, shows good performance when traffic is either un-congested

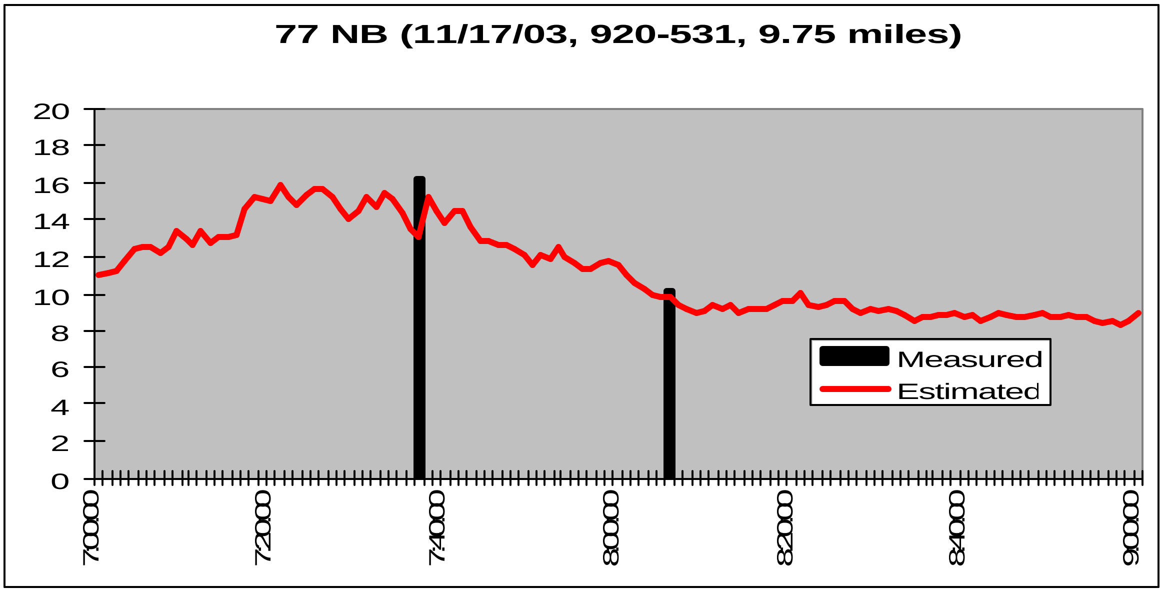

Figure 3.2.3 Comparison between measured and off-line estimated travel times (77NB)

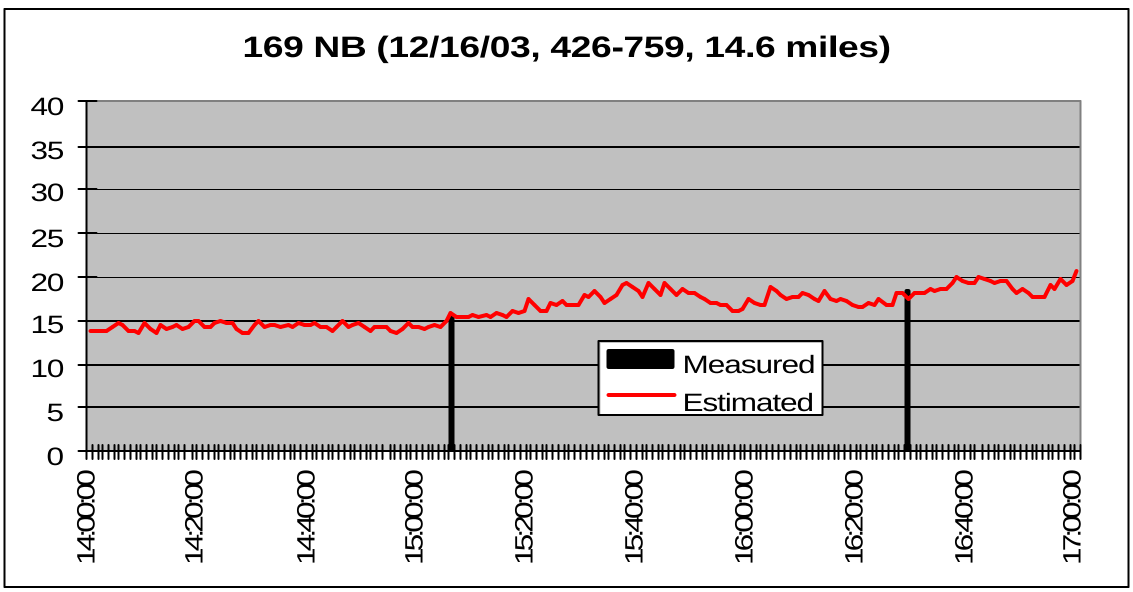

Figure 3.2.4 Comparison between measured and off-line estimated travel times (169NB)

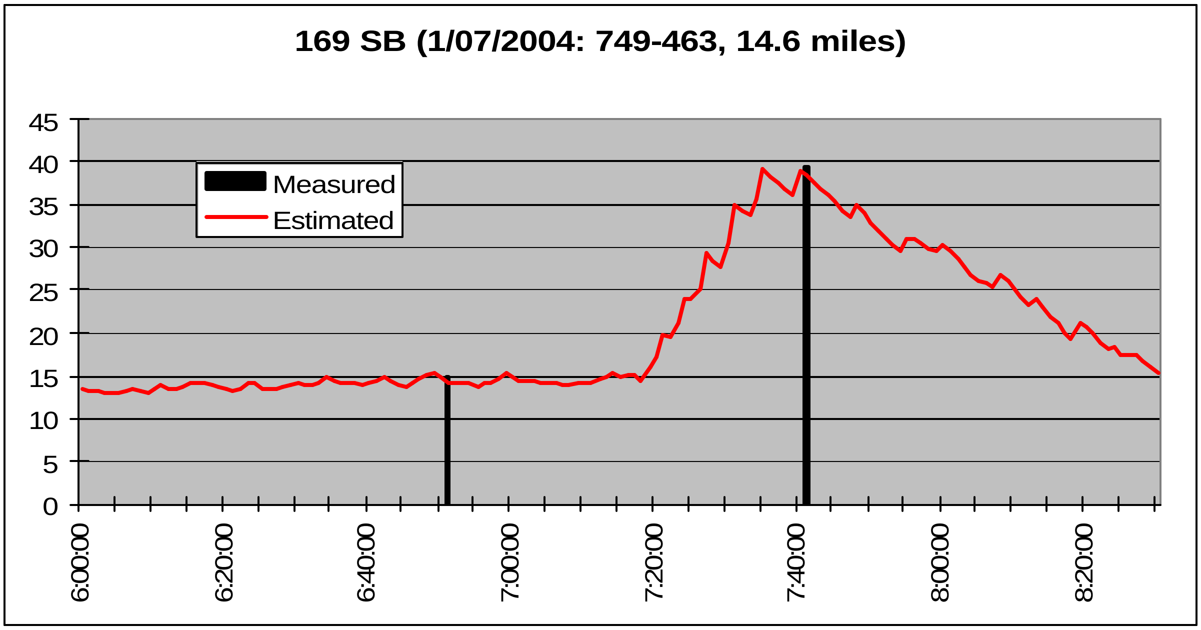

Figure 3.2.5 Comparison between measured and off-line estimated travel times (169SB)

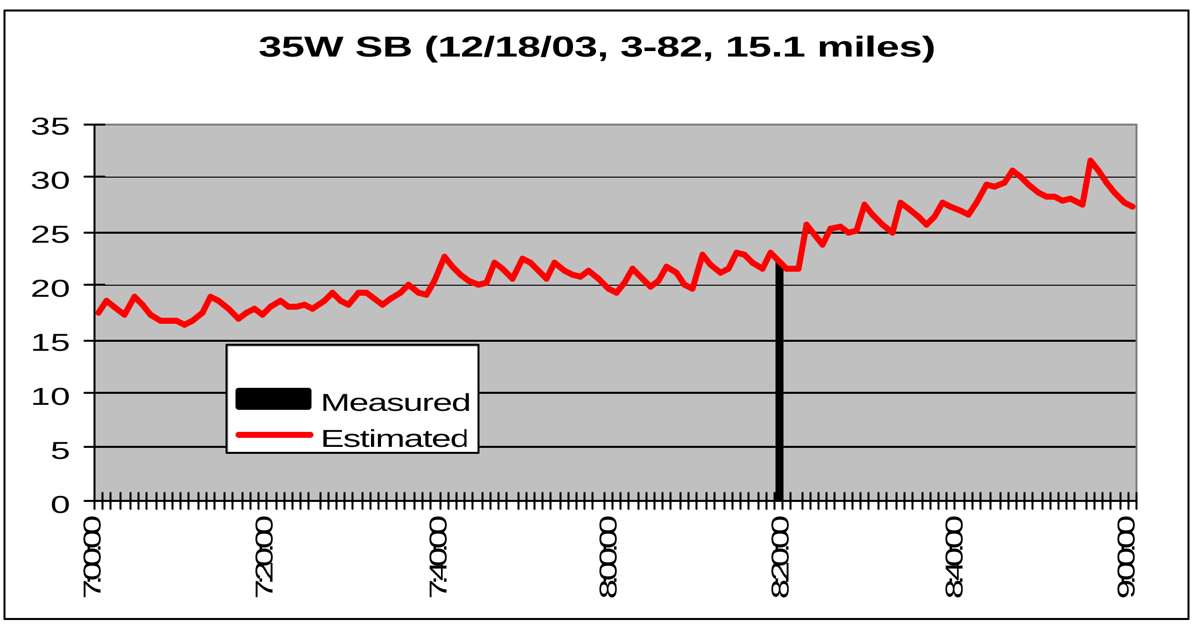

Figure 3.2.6 Comparison between measured and off-line estimated travel times (35W SB)

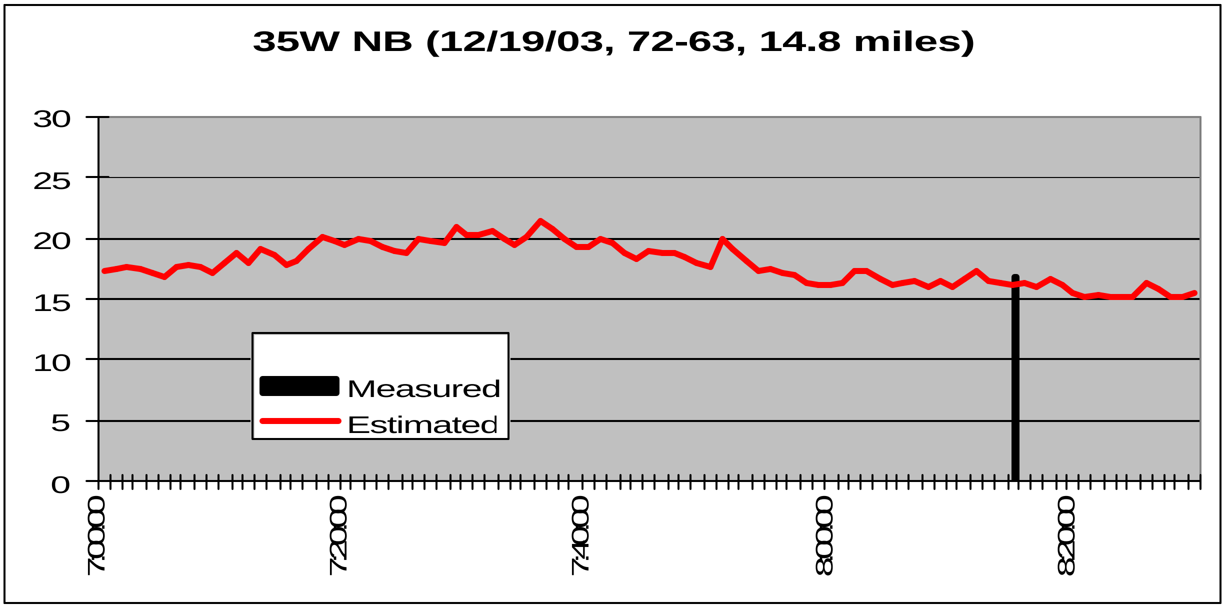

Figure 3.2.7 Comparison between measured and off-line estimated travel times (35W NB)

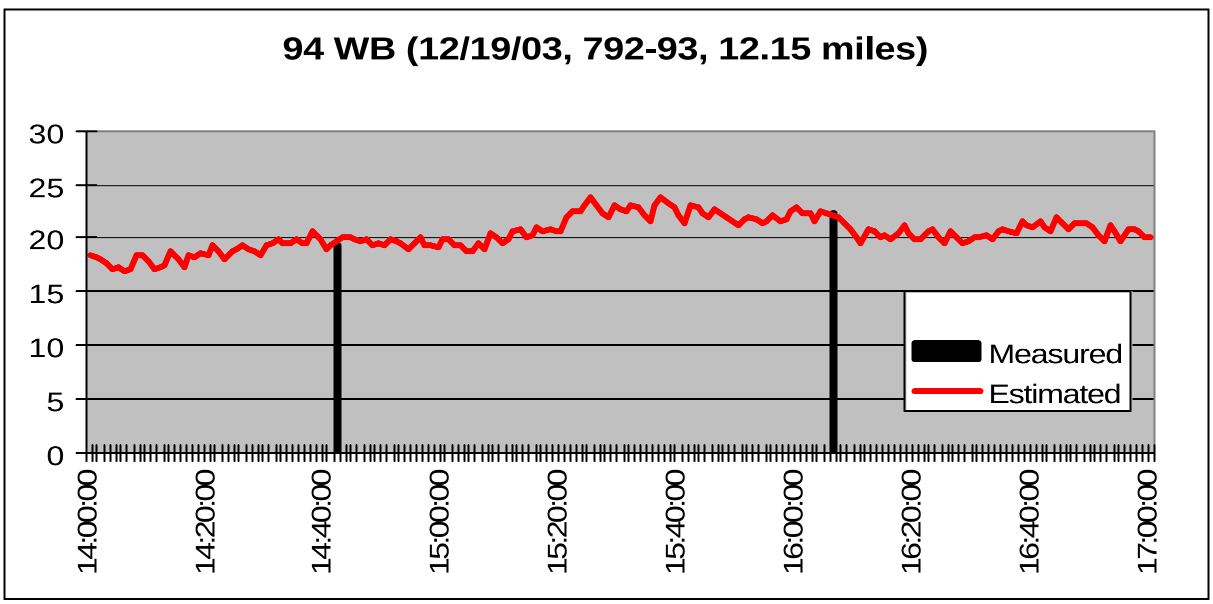

Figure 3.2.8 Comparison between measured and off-line estimated travel times (94WB)

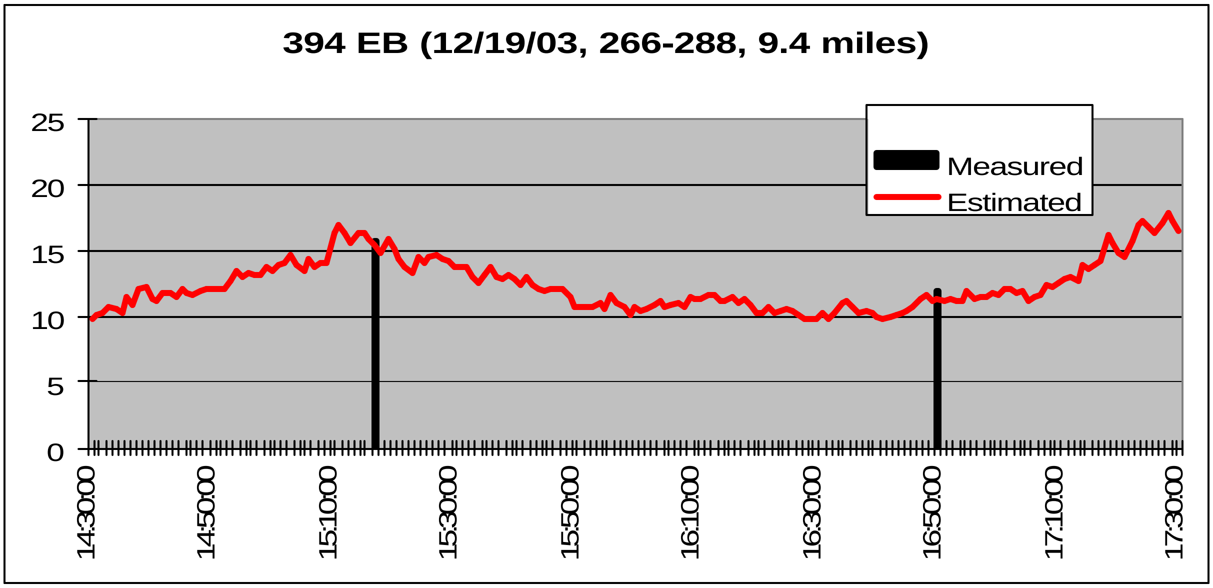

Figure 3.2.9 Comparison between measured and off-line estimated travel times (394EB)

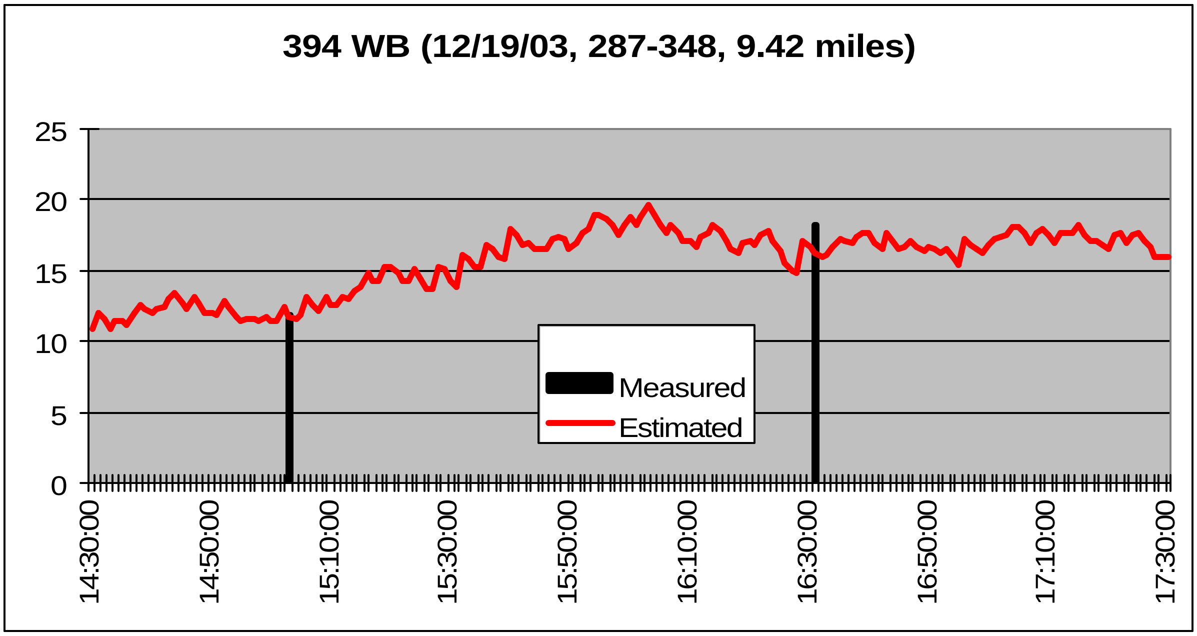

Figure 3.2.10 Comparison between measured and off-line estimated travel times (394 WB)

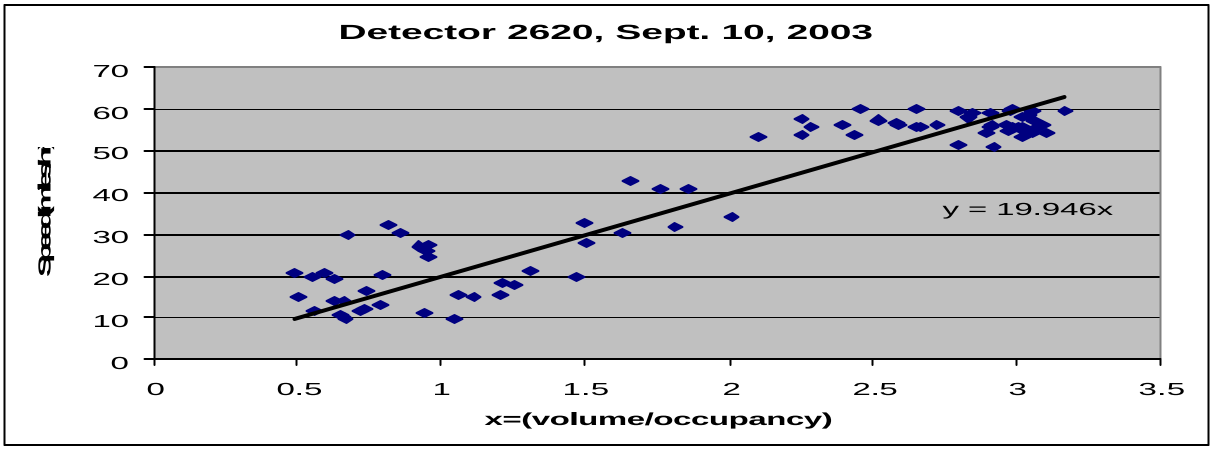

Figure 3.3.1 Correlation between speed and volume/occupancy (loop 2620)

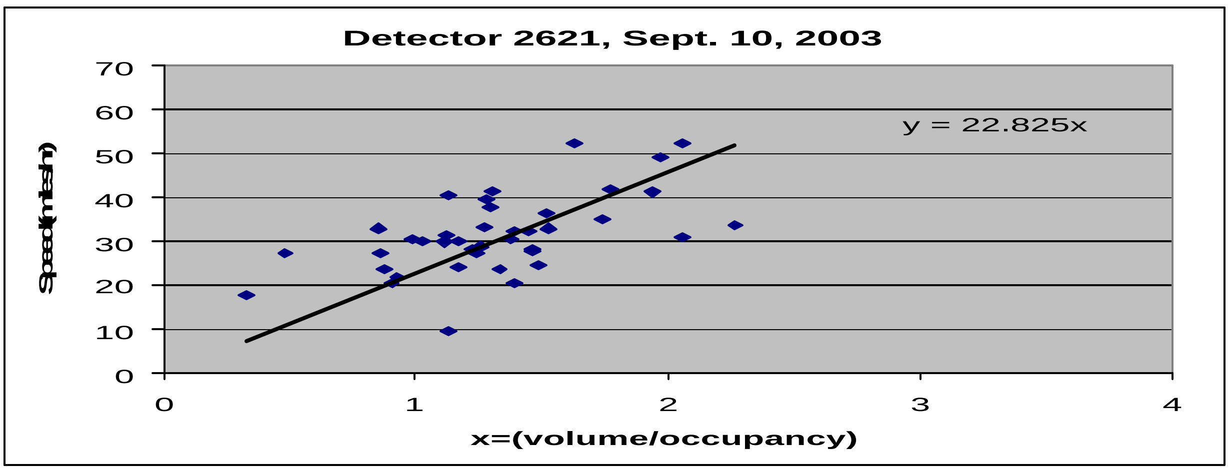

Figure 3.3.2 Correlation between speed and volume/occupancy (loop 2621)

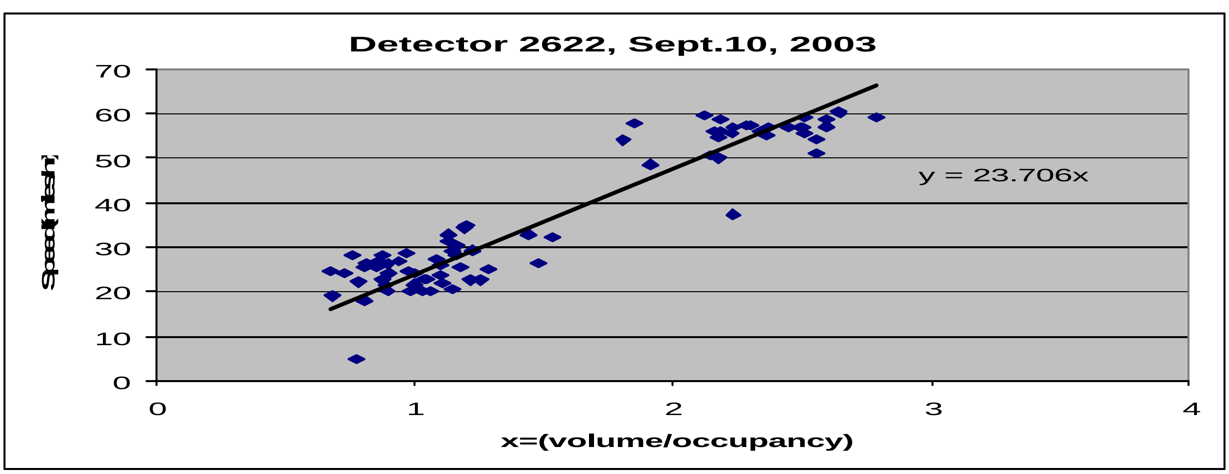

Figure 3.3.3 Correlation between speed and volume/occupancy (loop 2622)

or congested during the time period when the trip occurs, while significant amount of discrepancies between predicted and actual travel-times are shown during the transition periods, i.e., traffic state changes from un-congested to congested or vice versa. Figure 3.4.3 show the simplified situations when those discrepancies could be very substantial when travel times are predicted with only current speed measurements on a given route. As shown in this figure, the amount of the discrepancy can vary depending on the future traffic conditions, including the speed and type of the shock-waves, the level of congestion, changes in traffic demand and incidents that can happen after the travel time is predicted for a given route. While predicting travel times based on 'predicted traffic conditions' would be an ideal approach, the inherent randomness in traffic makes prediction extremely difficult. While some researchers proposed the use of historical data for the prediction of travel times, the accuracy of those methods can be significantly affected by the nature and types of historical data, which needs to be continuously updated.

In this study, an enhanced version of the snap-shot-speed based algorithm is developed and proposed for future consideration. The enhanced method adjusts the travel times determined by the conventional snap-shot-based algorithm as follows:

$$T_{p,t} = a_t * T_{s,t}$$

where, $T_{p,t}$ = Predicted travel time for a given route at time t,

$T_{s,t}$ = Snap-shot-speed based travel time calculated at time t,

$a_t = a * \exp[b*(I_t-O_t)/I_t]$

I_t = total sum of traffic volume entering the travel time route during time t-1 to t,

O_t = total traffic volume exiting the travel time route during time t-1 to t,

a, b = parameters

The above method tries to adjust the snap-shot-based travel time with expected traffic conditions during a short-term period with the measurable data, i.e., total volume entering and exiting a given travel time route.

The proposed method was tested off-line at the 77 northbound corridor with the parameter values calibrated with the data from January, 2004. Figures 3.4.4-3.4.6 show some of the test results of the proposed method with the parameter values calibrated with the data from January 2004. As indicated in those figures, the enhanced method shows more adaptability during the transition periods of congestion than the snap-shot-based method, while for the un-congested periods the performance of two methods are very similar.

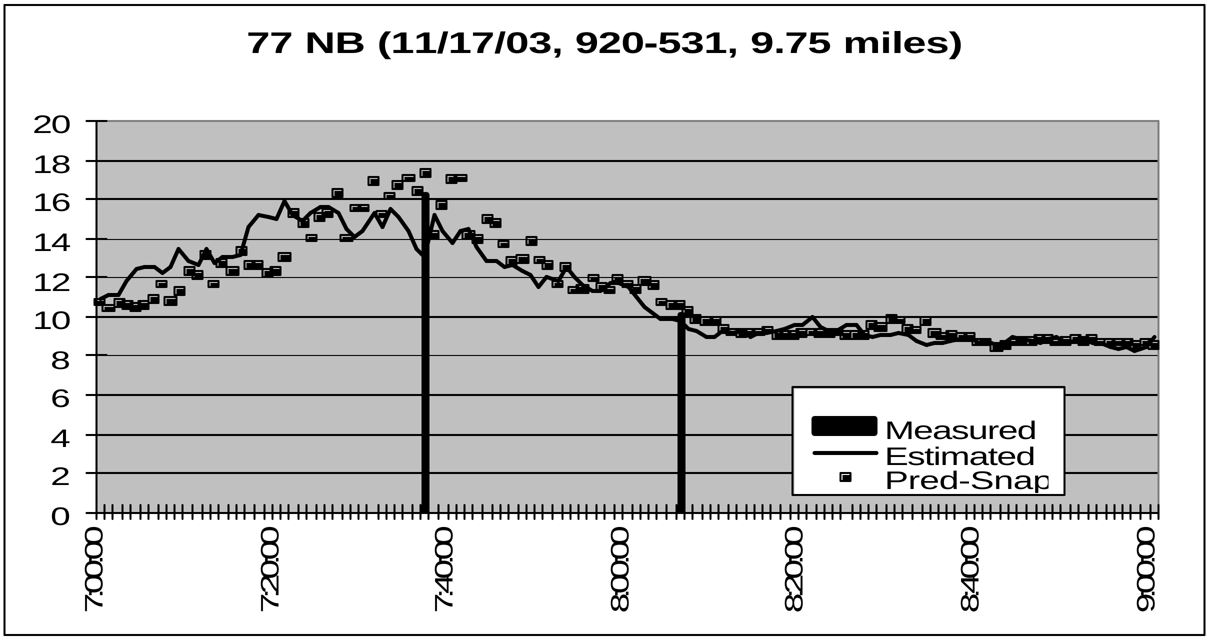

Figure 3.4.1 Off-line test results of the snap-shot-speed based method (77NB, 11/17/03)

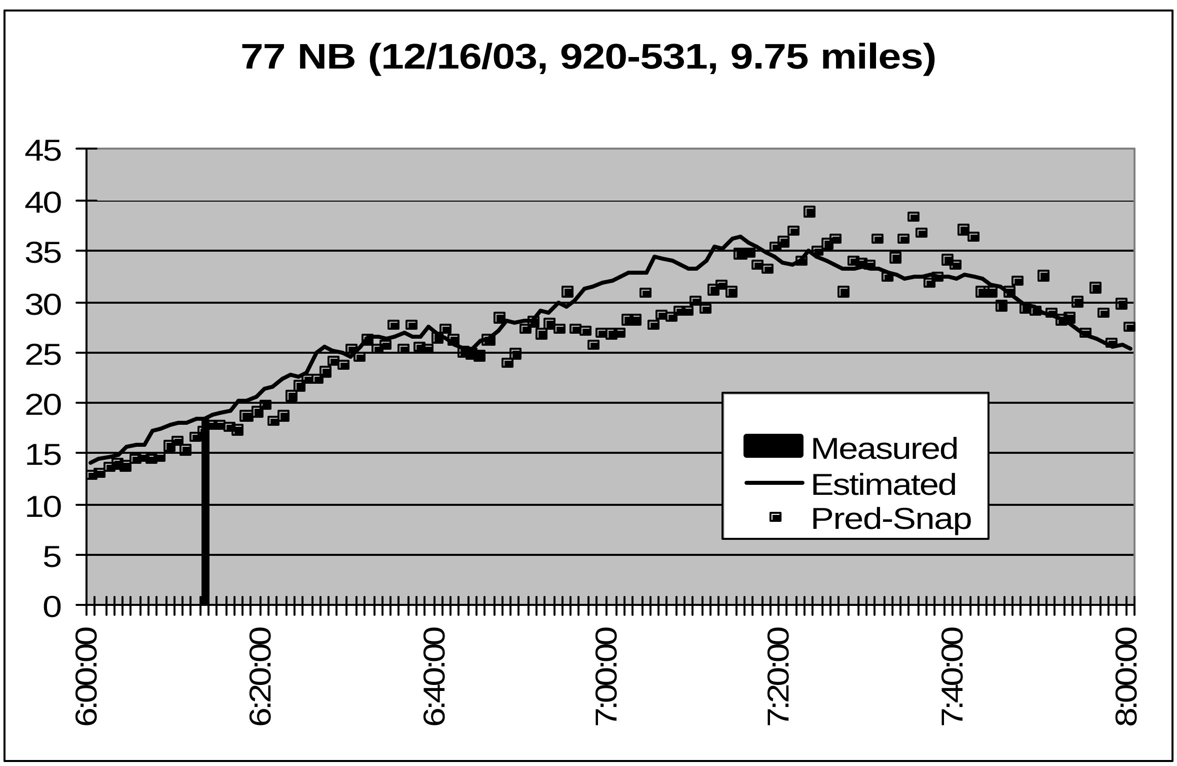

Figure 3.4.2 Off-line test results of the snap-shot-speed based method (77NB, 12/16/03)

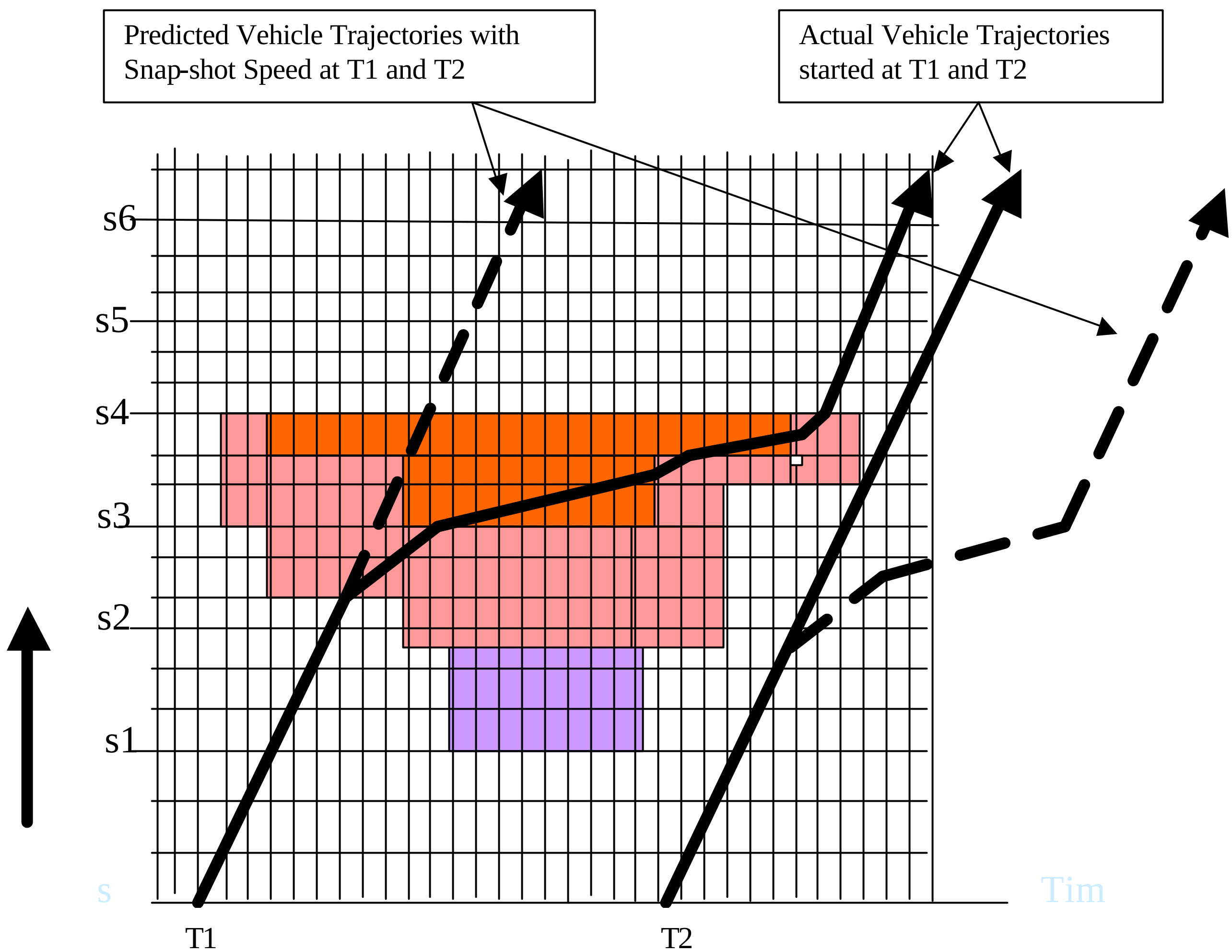

Figure 3.4.3 Potential discrepancies between Predicted and Actual Vehicle Trajectories based on snap-shot speed during congestion transition periods

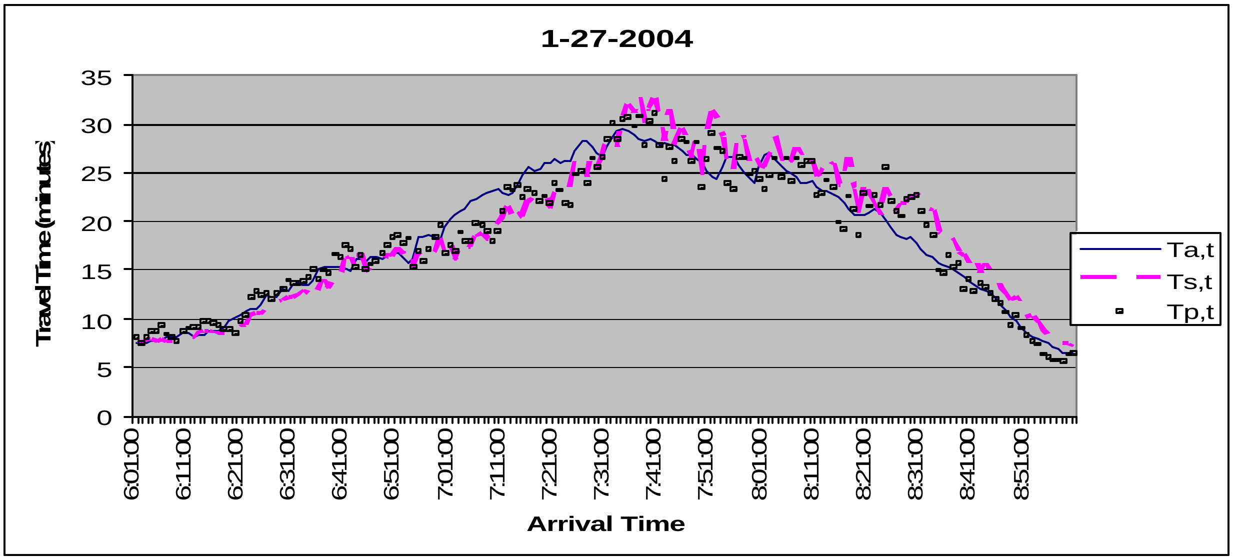

Figure 3.4.4 Comparison of travel time prediction results, 77 NB, 920-531, 1/27/04

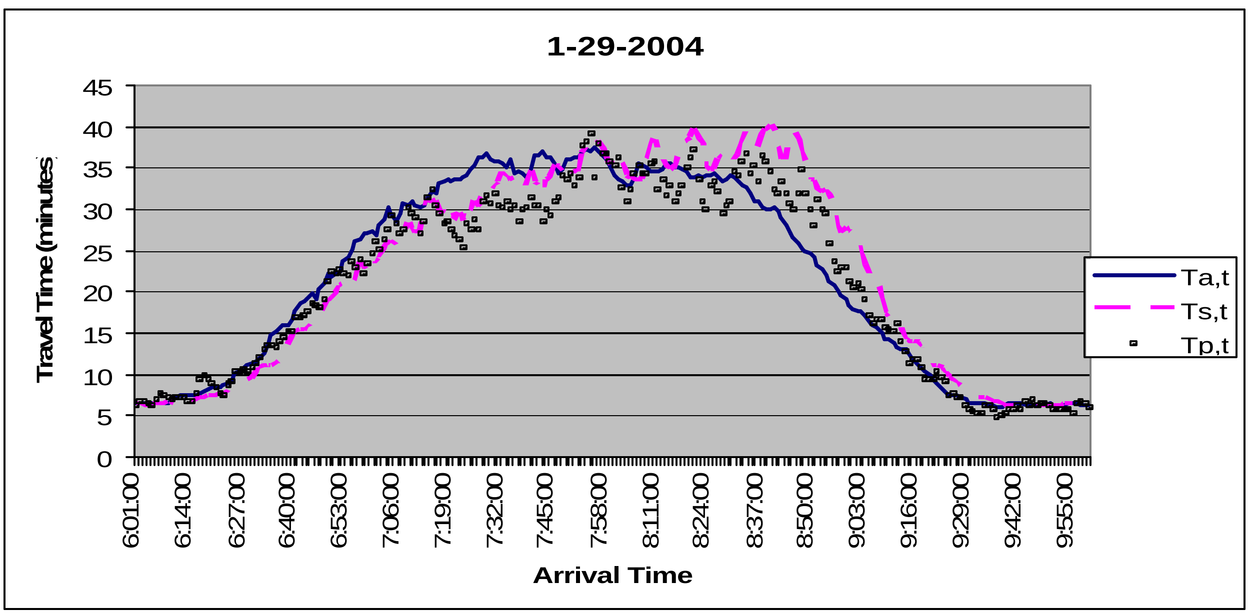

Figure 3.4.5 Comparison of travel time prediction results, 77 NB, 920-531, 1/29/04

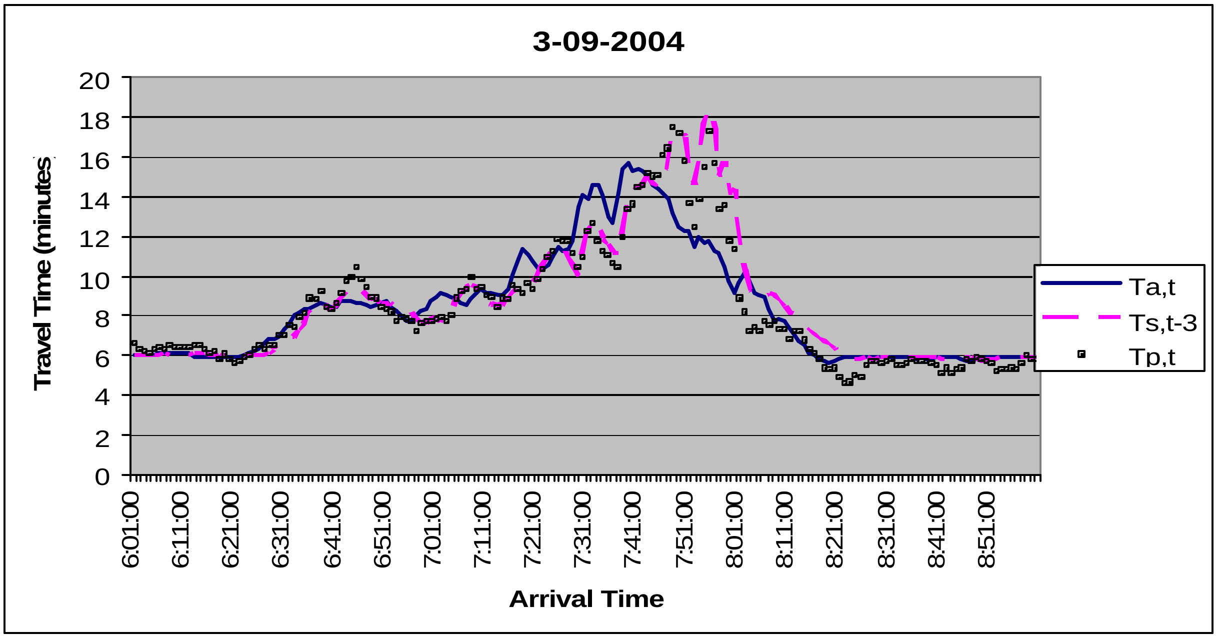

Figure 3.4.6 Comparison of travel time prediction results, 77 NB, 920-531, 3/9/04

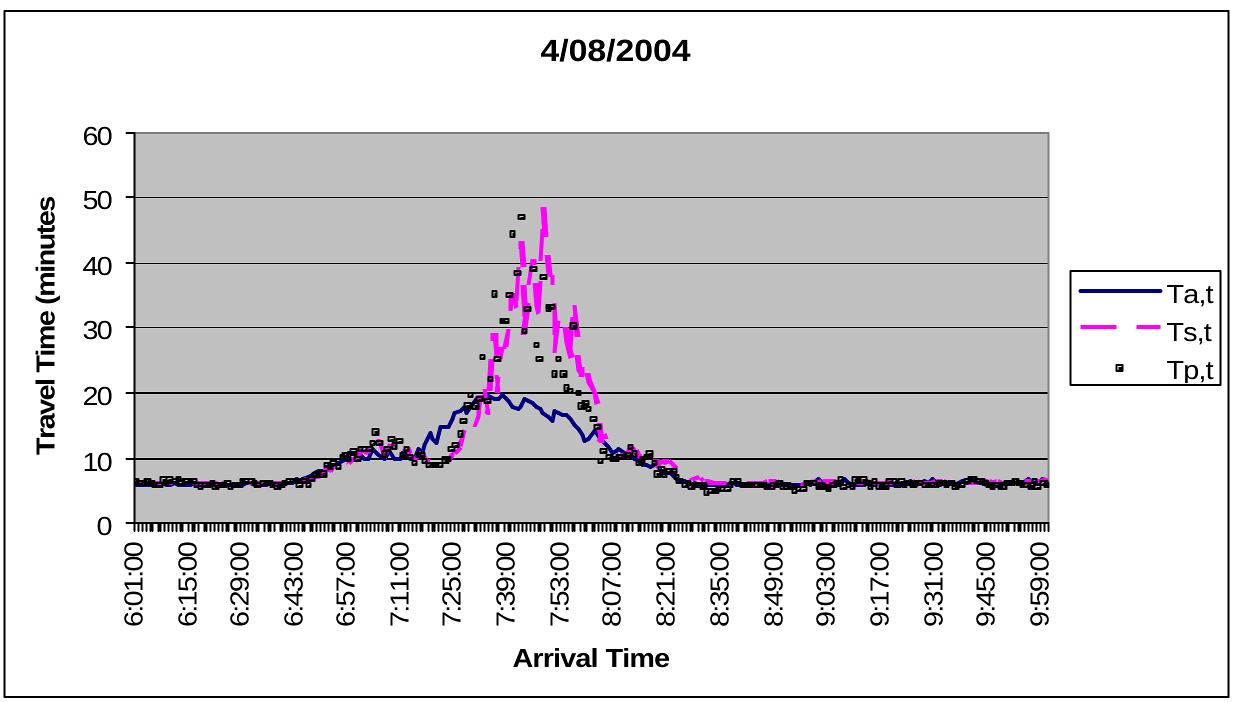

Figure 3.4.7 Comparison of travel time prediction results, 77 NB, 920-531, 4/8/04

4. CONCLUSIONS AND FUTHER RESEARCH NEEDS

The application results of the Dynasmart-P model indicate that it's feasible to use a dynamic network assignment model to develop and evaluate evacuation strategies in a large urban network environment. The qualitative testing results with the study network show the possibility of calibrating the model with the data currently available for a given network. The example simulations of different network configurations to evacuate the downtown traffic during an emergency situation indicate that the access capacity to the outbound freeway network is the critical issue in reducing the evacuation time in the downtown area. For example, the effectiveness of the contra-flow operations with the outbound freeway links showed significant improvements when the capacities of the key entrance ramps in the downtown area were also increased. Due to the limitations in the resource and time, a comprehensive analysis was not possible in this study to address various possibilities in terms of network configurations and driver behavior. They include the driver familiarity to the network, route-choice patterns and traffic behavior under emergency situations with/without real-time information, time-delays in configuring network for evacuation and different signal operational strategies. The estimation of the evacuation demand under dynamically changing environment is another important issue that needs to be addressed in the near future.

The off-line testing results of the travel-time estimation strategy developed in this study for freeway travel-times showed good performance between predicted and actual measured travel times under steady-state traffic conditions, either uncongested or congested. It was also noted that the performance of the proposed snap-shot-speed based method could degrade when traffic flow is in a transition period, i.e., when traffic condition rapidly changes because of demand variations or incidents. However, for the freeway sections whose length are less than 11-12 miles, most of snap-shot-speed based predictions, i.e., up to 85% in most cases, have less than 20% difference from actual measured values. It was further noted that the amount of difference can vary depending on the number of lanes in a given travel time route. The estimated speed values with the volume and occupancy measurements from single loop detectors also showed reasonable accuracy when the detector field length values were properly calibrated. While maintaining the high level of detection availability and accuracy is essential for the on-line estimation of travel times, the limitations of the snap-shot-speed-based methods in dealing with the transition periods need to be continuously studied. An automatic and systematic feedback system to check and review the performance of the travel-time estimation algorithm would also be needed for effective operations.

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