

1. REPORT NUMBER CA10-0286	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
4. TITLE AND SUBTITLE Integrated Work Zone Traffic Management		5. REPORT DATE 09012011
7. AUTHOR Michael Zhang and Sean Z. Qian		6. PERFORMING ORGANIZATION CODE
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute of Transportation Studies University of California Davis Davis, CA 95616		8. PERFORMING ORGANIZATION REPORT NO. UCD-ITS-RP-11-06
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research and Innovation, MS-83 1227 O Street Sacramento CA 95814		10. WORK UNIT NUMBER
		11. CONTRACT OR GRANT NUMBER 65A0286
		13. TYPE OF REPORT AND PERIOD COVERED Final Report
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Nonrecurrent traffic congestion caused by construction work constitutes a large proportion of traffic congestion on highways. In a previous project, TO 5300, we developed a comprehensive work zone traffic impact assessment procedure using a series of state-of-the-art dynamic network analysis tools as building blocks and implemented it into a work zone traffic impact assessment software package called NetZone. This software package is capable of estimating time-dependent travel demand based on link counts, estimating demand reduction in response to work zone delay and various traffic management measures, showing traffic congestion level in the network over time, and providing network-wide traffic performance measures.

In this project, we improved the modeling functions of NetZone, added additional modeling elements such as HOV lanes, and reorganized and enhanced the graphical user interface of NetZone. Moreover, we provided a full scale application of the improved NetZone, the evaluation of the Fix-I5 reconstruction project in the Sacramento Metropolitan Area, showing that one can use it to study a reasonably large network in a fraction of time that would have been taken if one used a micro-simulation package for the same network.

The developed methods and tools can help better plan and operate construction activities on highways, and more effectively manage traffic to reduce travel delays.

17. KEY WORDS Rehabilitation, construction work zone, traffic impact, work zone traffic management, NetZone, traffic congestion, traffic diversion, traffic simulation.	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 2216. Access and use of Netzone can be obtained by contacting the author at: hmzhang@ucdavis.edu	
19. SECURITY CLASSIFICATION (of this report) Unclassified	20. NUMBER OF PAGES 101	21. COST OF REPORT CHARGED N/A

**State of California Department of Transportation
Division of Research & Innovation
Office of Technology Applications**

INTEGRATED WORK ZONE TRAFFIC MANAGEMENT

Final Report

UCD-ITS-RP-11-06

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Sep 01, 2011

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ACKNOWLEDGMENT

We wish to thank Hamid Rifaat, Andrew Lee and Haniel Chung from Caltrans Division of Research for their project management support.

The NetZone product made extensive use of models, algorithms and codes developed in several doctoral research supervised by Professor Michael Zhang. Their authors, Drs. Allen Xiaojian Nie, Yue (Marco) Nie, and Wei Shen had directly or indirectly contributed the development of NetZone. Their contributions are gratefully acknowledged.

Executive Summary

This project is a continuation of TO 5300 “Integrated Construction Zone Traffic Management”. In TO 5300, we developed a comprehensive work zone traffic impact assessment procedure using a series of state-of-the-art dynamic network analysis tools as building blocks. This procedure was then implemented into a work zone traffic impact assessment software package called **NetZone**. Although **NetZone** shows great promise in our preliminary evaluation study, it is nevertheless a prototype software that needs further development and refinement before it can be widely adopted as a work zone analysis tool for large-scale networks. In this project, we improve the traffic analysis models embedded in **NetZone**, add traffic control models and emission models to **NetZone**, and reorganize and improve the graphical user interface of **NetZone**. With such enhancement, the new **NetZone** becomes more robust, powerful and easier to use, and can be applied to more complicated work zones under more general network settings.

In a nutshell, **NetZone** is a dynamic network analysis tool capable of estimating network-wide traffic impact for any general networks consisting of freeway, arterials and local streets. The new **NetZone** comes with the following features,

- **Representations of general networks:** this includes various types of roads and junctions, such as freeways, arterials, signal controlled intersections or metered ramps. This newer version of **NetZone** also added the capability of modeling High Occupancy Vehicle (HOV) facilities.
- **Added capability of modeling environmental impact:** the new **NetZone** implements speed based emission and fuel consumption models that can directly produce link based or network wide emission and fuel consumption statistics for several pollutants, such as HC, CO, CO₂ and NO_x.
- **Increased capabilities of modeling traffic control and demand management:** the new **NetZone** now has a more robust module to model various types of traffic control actions, such as pre-timed intersection signal timing and ramp metering, signal coordination,

adaptive traffic control (vehicle actuated control and ALINEA ramp metering), and adaptive control integration (locally synchronized control or LSC). It also models the pairwise or overall traffic demand reduction induced by traveler information.

- **State of the art dynamic traffic model:** the new NetZone implements the classic macroscopic kinematic wave traffic flow model and state of the art junction models. It introduces a hybrid routing strategy where travelers separate into two groups, those who stick to their routes (habitual travelers) and those who change their routes in response to changing traffic conditions (adaptive travelers). The ratio between habitual and adaptive travelers can be adjusted/calibrated to capture the degree of traffic diversion and obtain realistic simulation results.
- **Streamlined data preparation and model calibration:** the new NetZone provides several options to prepare a network and its data related to a work zone project and various study scenarios. Most often, one can directly import a network from mainstream GIS software, then edit/change the network and its data with an easy-to-use graphical user interface. In particular, it comes with a state-of-the-art OD estimation module that helps users to obtain time-dependent OD demands, which often greatly shorten the calibration process. Several diagnostic tools, such as network connectivity and animation of traffic conditions through simulation replay, are also implemented to facilitate model calibration.
- **Powerful tools for project analysis and report generation:** NetZone provides several visualization tools to facilitate the analysis of project results. These include the cumulative flow diagrams, density/speed contour plots, link queuing/delay plots, and above all an animation tool showing 'live' traffic through re-playing simulation results, from which one can identify hot congestion spots. The animation tool is particularly useful during model calibration to spot problems such as gridlock.
- **Extensible framework:** NetZone actually has all the essential elements of a general purpose dynamic traffic assignment/simulation software and can be made to suit a variety of applications besides work zone studies. Examples include integrated corridor traffic management and environmental impact assessment of major transportation projects.

Finally, these features of NetZone were illustrated in a case study, in which NetZone is used to assess the traffic impact of an actual major full-closure reconstruction project (The Fix-I5) in a large-scale network, i.e., the network of the Sacramento Metropolitan Area, with satisfactory

results: it provided good estimates of dynamic O-D demand for the periods before, during, and after the Fix-I5 project and closely reproduced the congestion levels during the reconstruction (its estimated travel times for major affected routes are much closer to observed ones than those obtained using other tools). While **NetZone** only underwent limited testing and evaluation, this initial application result is encouraging.

Chapter 1

Introduction

1.1 Project background, objective and scope

In California, the highway system as a whole has around 16,662.16 miles¹, 90 percent of which were built between 1955 and 1970 with the typical 20-year design life. A large portion of these highways has been exposed to heavier traffic volumes and loads than it was originally designed for. Therefore, there is a great need to rehabilitate or reconstruct aging highway sections in the coming decade in order to maintain a safe, reliable, environment-friendly and efficient highway network. However, the closure of highway facilities for maintenance work can cause a substantial reduction in its operating capacity, and thus may result in not only severe traffic congestion and safety issues, but also significant environmental impact. It is essential to set up a proper construction scheme and a comprehensive traffic mitigation plan. First, the construction scheme provides time windows in time of days where a certain part of highway facilities are closed for rehabilitation or reconstruction. Second, work zone traffic management includes, but not limited to, work zone traffic signs (speed limit and lane width), web-based pre-trip traveler information systems, highway advisory radio, variable message signs, integrated traffic control. The construction scheme and traffic plan should altogether minimize the traffic delay and environmental impact it may bring to the network and travelers.

This project is a continuation to TO 5300 “Integrated Construction Zone Traffic Management”. In TO 5300, we developed a comprehensive work zone traffic impact assessment procedure using a series of state-of-the-art dynamic network analysis tools as building blocks. This procedure is then implemented into a work zone traffic impact assessment software package called NetZone. The main accomplishments of TO 5300 are:

- **A systematic review of current work zone traffic analysis tools.** We identified

¹According to www.cahighways.org/stats

four types of tools often used in work zone traffic analysis: queue-based tools (e.g., Demand/Capacity and QuickZone), transportation planning models (e.g., TP+, EMME/2), macroscopic freeway simulation models (e.g., FREQ), and microscopic traffic simulation models (e.g., Paramics). These tools vary widely in terms of key assumptions, input data, outputs produced and computational performances. Our review shows that there lacks an effective work zone traffic analysis procedure that possess the following characteristics: 1) model different geographic scopes, e.g., isolated work zones, corridor, multiple work zones in a complicated network; 2) model diverse traffic management measures e.g., change in signal timing, traveler information system, speed limit, lane re-stripping, etc., 3) model travelers' responses to capacity reduction in work zone and to management measures e.g., no response, divert to an alternative route, change departure time, cancel the trips, switch to other modes, etc.; 4) produce detailed performance measures e.g., aggregate indices (e.g., total travel time, delay, maximal queue) and disaggregate indices (e.g., delay and queuing on specific links); and 5) be easy to use, easy to collect input data, calibrate parameters, and set up the model, provide reasonable results with acceptable computational overhead. We took the macroscopic simulation approach to develop the tool that meets the above requirements.

- **Investigation on travel demand shifts.** We studied the demand patterns before and during construction for two rehabilitation projects: the I-710 Long Beach project and the I-15 Devore project. Our study reveals that 1) demand diversion rate seems to be highly related to network topology, i.e., the availability of detour routes, and the dominant travel purpose through the work zone area; 2) the time of construction (weekend or weekday), use of traveler information system, previous traffic condition, and capacity reduction proportion may affect diversion, but the effect is not pronounced in these two projects; and 3) compared to demand reduction, the peak spreading effect is relatively small (I-15 project, slight shifts; I-710 project, trivial).
- **Developed a general purpose work zone traffic analysis software NetZone.** We proposed a work zone traffic analysis procedure for quickly assessing network-wide traffic impact of a given construction plan. This procedure includes demand estimation, dynamic traffic assignment, macroscopic traffic simulation, and scenario analysis. We implemented this procedure into a software package called NetZone, which is a powerful, versatile and user-friendly analysis tool for work zone projects that takes into account 1) demand changes, 2) route diversions, 3) ramp metering, 4) arterial traffic operations,

and 5) traveler information. It provides detailed statistics on delays and queues on specific links and routes as well as the entire network. Because it is macroscopic, it consumes much less computational and human resources to calibrate and apply than microscopic simulations, and because it is dynamic, it captures peak spreading and queuing. With suitable modifications, it can also be used as a general purpose corridor study tool.

- **Evaluated NetZone with the SR-41 case study.** We carried out a case study on a stretch of SR-41 to evaluate NetZone. SR-41 is a network that took months to build and calibrate in Paramics. With NetZone, it is coded and calibrated in weeks, and four construction/traffic management scenarios were evaluated and the initial results were encouraging.

Although NetZone shows great promise in our preliminary evaluation study, it is nevertheless a prototype software that needs further development and refinement before it can be widely adopted as a work zone analysis tool for large-scale networks. The objectives of this continuation to TO 5300 are twofold; 1) Improve the traffic analysis models embedded in NetZone, and add traffic control models and emission models to NetZone. With such enhancement, the new NetZone can take into account more complicated work zone plans, and be applied in a more general network than before; and 2) address some of the most pressing needs in Graphical User Interface (GUI) and make NetZone more robust and bug-free to be ready for official release.

NetZone developed in this project is expected to help traffic engineers to accurately estimate and compare the work zone traffic impact under different construction plans and traffic management scenarios. A best work zone plan should not only reduce the extra traffic congestion brought by construction, but also minimize its impact to the environment. The deliverables contribute to Caltrans' goals of increasing safety and productivity of its highway network, increasing productivity and cost reduction of pavement maintenance, rehabilitation and reconstruction program, as well as reducing carbon footprint.

1.2 Project tasks in the continuation to TO 5300

This continuation proposal is divided into the two project phases, with Phase I enhancing the embedded modeling and analysis functions of NetZone, and Phase II improving GUI, validating the models with case studies in large-scale networks, conducting a training workshop, and producing a user manual and a final project report.

The specific tasks of this project include,

- Underlying traffic model

Currently NetZone models a work zone as a special type of incident with a reduced capacity for the work zone segments. In this continuation, we modify the work zone data structure and related traffic flow models in NetZone to incorporate work zone length and speed limit reduction for the construction area. Currently NetZone does not model High-Occupancy Vehicle (HOV) or other special lanes. We will upgrade NetZone to include HOV lanes and use the system performance of HOV travelers as one of the indicators to evaluate work zone plans. We also improve the traffic route choice models and develop algorithms to generate Origin-Destination connectors to the network.

- Traffic control

The traffic control elements in NetZone will be expanded. Currently it supports fixed-timing signal control and ramp metering algorithm ALINEA. We plan to implement actuated signal control, stop-sign and yield control at intersections, pre-timing ramp metering, and improve the lane-merging (for permitted left turns and right turn on red) logic in NetZone. Local Synchronization Control (LSC), i.e. coordinations between adjacent intersection signals or ramp metering, is also implemented to provide more advanced control strategy.

- Emission

We will implement emission models in NetZone. The total network fuel consumption and emissions in hydrocarbon, CO, CO₂ and NO_x are computed by NetZone to evaluate work zone plans.

- GUI

We reorganize the project task flow in NetZone through consolidating and streamlining the dialog boxes, so as to make it easier to use and less prone to malfunctions. We also improve the network visualization with its editing tools and add the conversion tool from/to ERSI shape files. Another important part in this enhancement is to provide diagnostic functionalities for potential input errors and network codings inconsistency.

- A new work flow

Since enhanced traffic models are incorporated and new GUI is developed, we will set a new work flow for NetZone. We also perform calibration and validation work to check the validity of the underlying models in NetZone, and to diagnose potential modeling problems.

We'll also conduct extensive software testing to rid **NetZone** of potential bugs, and to assess its performance under various testing scenarios.

- Significant improvement on computation efficiency

It would be essential to improve the computational efficiency in **NetZone**, particularly on network simulation, simulation replay and visualization of measures on both the entire network and critical network components.

- Case study: Sacramento Metropolitan Area

We apply **NetZone** in a real work zone project in Sacramento Metropolitan Area, Fix I-5 Project, to demonstrate the capability of **NetZone** in assessment of work zone impact in large-scale networks.

- User's manual and a quick tutorial

We provide user's manual and a quick tutorial of **NetZone**.

This report is organized into six chapters. Chapter 2 proposes new underlying traffic models embedded in **NetZone**. Chapter 3 focuses on the travel control elements in **NetZone**. It discusses how all types of signal control and ramp metering are implemented in **NetZone** in terms of models and GUI. Chapter 4 discusses the emission model we adopted for **NetZone**. Chapter 5 describes several major parts of **NetZone** GUI that are developed or enhanced. Chapter 6 presents the implementation details of the new work flow of **NetZone** and shows that the efficiency has been greatly improved in the new version. Chapter 7 gives an overview of the new **NetZone** and we apply **NetZone** in a real work zone project, Fix I-5 Project, in Chapter 8 to demonstrate the capability of **NetZone** in assessment of work zone impact in large-scale networks.

The accompanying user manual and a quick tutorial for **NetZone** will be provided in separate documents.

Chapter 2

Traffic models

In this chapter, we present four new traffic models implemented in NetZone, a route choice model, work zone models, an Origin-Destination (O-D) connector model and an High-Occupancy Vehicle(HOV) model. All four new models are incorporated in the traffic simulation, the core of NetZone. We upgrade NetZone with a more realistic routing choice model and new work zone models that can be applied to evaluate more general work zone schedules. We also include HOV lanes and use the system performance of HOV travelers as one of the indicators to evaluate work zone plans. A new O-D connector model help reduce the artificial congestion on the links adjacent to connectors, and it also can effectively prevent gridlock from occurring in some cases.

2.1 The route choice model

2.1.1 The model

Route choice model is central to the traffic simulation. It determines the routing patterns for each of the travelers depending on their generalized travel costs. The conventional routing pattern is usually referred to as a user-equilibrium (UE) flow pattern. In the dynamic context, there are generally two types of UE in the literature. One is the so-called Boston User Equilibrium (BUE) (Friesz et al. 1993), which is an adaption of the static Wardropian UE. It assumes a traveler chooses the shortest route only based on the prevailing traffic condition at the time of his choice decision (Kuwahara & Akamatsu 2001). The other UE type is the so-called Predictive User Equilibrium (PUE). Under this behavioral assumption, travelers choose the shortest route based on “anticipated” travel times, or travel times that they actually experienced from previous days. The result is a UE in which the actual travel times/costs for travelers from any O-D pair are minimal and identical (Friesz et al. 1993), regardless the routes they take.

In real life, travelers’ route choice behavior is likely to be more complex than what was

assumed in both BUE and PUE. For example, travelers may not consider all the possible routes but have several pre-trip routes in mind prior to their departure, which are selected from their day-to-day traveling experiences. Moreover, these pre-selected routes may not be user-optimal ones. Although travel time and schedule delay costs are dominant factors in travelers' route choice decisions, several other factors, such as road accessibility, pavement conditions, and so on, may influence their decisions as well. Besides these factors, a traveler's personality should also play an important role in his or her route choice. Thus real traffic is more likely to be the product of various types of choice decisions rather than cost-minimizing BUE or PUE applied uniformly across the entire traveling population. In addition, PUE requires an iterative procedure where traffic simulation is implemented in each iteration, which is apparently highly time consuming for large-scale networks. Both PUE and BUE can easily fall into the network gridlock where no traffic can move due the unrealistic assumption on route choices in large-scale networks. Therefore, a new route choice model that can produce realistic traffic performance if properly calibrated and result in less computational complexity for simulation is highly desirable. Now we present our new route choice model.

Suppose the network is represented by a directed graph that includes a set of nodes, N , and a set of links, A . Let a denote the link index, $a \in A$. Let R and S denote the set of origin nodes and destination nodes, respectively. $r - s$ represents an O-D pair, where $r \in R$ and $s \in S$. K_t^{rs} and q_t^{rs} is the set of paths and O-D demand for an O-D pair $r - s$ departing at time t , respectively. The generalized travel cost of commuters departing at time t on path p of O-D pair rs , $c_p^{rs}(t)$, consists of I number of terms ($w_{1,pt}^{rs}, w_{2,pt}^{rs}, \dots, w_{I,pt}^{rs}$) which represent those factors that travelers perceive on path p of O-D pair rs departing at time t (including travel time, schedule delay cost and toll) and are weighted by scalars λ_i ,

$$c_p^{rs}(t) = \sum_{i=1}^I \lambda_i w_{i,pt}^{rs} \quad (2.1)$$

Let $[0, T]$ be an assignment horizon (i.e., the analysis period). The network is assumed to be empty at $t = 0$. Corresponding to the assignment period, we define a loading horizon $[0, T']$, where T' marks the time when the network is cleared up. Furthermore, let ϕ_a denote an assignment interval, a discrete duration during which the departure flow rate for any O-D pair is assumed to be constant (m_a is the number of assignment intervals, i.e., $T = m_a \phi_a$). ϕ_l is the loading interval, a discrete duration during which network conditions are assumed to be stationary (a loading horizon consists of m_l loading intervals of uniform length, i.e., $T' = m_l \phi_l$). ϕ_a must be a multiple of ϕ_l .

We introduce two groups of travelers: travelers who are willing to deviate from their pre-determined routes and those who are not. The reason is simple. Some conservative travelers, once they determine which routes to take and get familiar with those particular routes, would rather stick to them than risking on finding new (or unknown) routes that may actually turn out to be worse than their previous routes, unless congestion they experience in their current routes becomes unacceptable to them. Those travelers are normally reluctant to deviate from their prescribed routes. We call this group of travelers **habitual travelers** ($1 - \theta$ percentage of travelers). On the other hand, some adventurous travelers are more willing to explore new routes in response to their travel experience and/or up-to-date traffic information. They may be equipped with devices that offer real-time navigation, or they may be familiar with the entire network and are able to change their routes to avoid the congestion. We call this group of travelers **adaptive travelers** (θ percentage of travelers). In a real network, the proportion θ , also referred to as the **Diversion Ratio**, may not be a constant and may change with respect to network conditions. For example, the diversion ratio can increase in the event of a major accident or highway reconstruction project. Nevertheless, we expect the diversion ratio to be relatively stable for a network at least in the short run barring the occurrences of various major incidents.

For the habitual travelers, their routes are determined based on a number of factors, such as travel distance, historical travel times, and personal preference for major streets and freeways. These routes, however, may not be the same as the dynamic User Equilibrium routes when everyone is a habitual traveler, since now mixed with adaptive travelers, User Equilibrium is no longer achievable. In **NetZone**, we assume those prescribed routes are K shortest paths for each pair of O-D with respect to the free-flow travel times. Let P_t^{rs} denote the set of those routes that habitual travelers departing at time t between O-D pair rs strictly comply. The proportion of travelers who use a path $p \in P_t^{rs}$ in the group of habitual travelers, also known as the prescribed route rate, is,

$$\pi_p(t) = \frac{\exp(-c_p(t))}{\sum_{p' \in P_t^{rs}} \exp(-c_{p'}(t))} \quad (2.2)$$

Therefore, the number of travelers who depart at time t between O-D pair rs and use path $p \in P_t^{rs}$ is,

$$q_p(t) = (1 - \theta)q_s^{rs}\pi_p(t) \quad (2.3)$$

For adaptive travelers, we assume that they always take their respective shortest path with respect to the instantaneous travel cost at each time interval. Adaptive travelers behave

in a similar way as in the en-route route choice model embedded in BUE (Friesz et al. 1993, Kuwahara & Akamatsu 2001), but the time period at which travelers update their shortest paths using the instantaneous travel cost can be relaxed from the assignment interval, ϕ_a in the BUE, to an arbitrary time interval in multiples of the loading time interval, i.e. $\gamma\phi_l$ (where γ is an integer). $\gamma\phi_l$ indicates how frequent the adaptive travelers are able to obtain up-to-date traffic information and choose an alternative route if necessary.

It is crucial to define the instantaneous travel time of link a at entry time t , $\tau_a(t)$, which equals $l_a/s_a(t)$ where $s_a(t)$ is the instantaneous travel speed of link a at entry time t and l_a the length of link a . Given the density of link a at time t , $k_a(t)$, $s_a(t)$ is estimated by,

$$s_a(t) = \begin{cases} u_a & \text{if } k_a(t) \leq k_{a,m} \\ \left(\frac{k_{a,j} - k_a(t)}{k_{a,j} - k_{a,m}} \right) \frac{C_m}{k_a(t)} & \text{if } k_a(t) > k_{a,m} \end{cases} \quad (2.4)$$

Where $k_{a,j}$ is the jam density of link a , $k_{a,m}$ the critical density and C_m the maximum flux of link a (also known as the capacity). If the density of link a at time t is smaller than $k_{a,m}$, then the instantaneous travel speed is the free-flow speed of link a , i.e. u_a ; otherwise, it equals the division of the flux of link a at time t by its density at time t where the flux can be solved using the triangular fundamental diagram of link a given $k_a(t)$.

This new route choice model no longer requires an iterative solution procedure as PUE does. Instead, a one-shot traffic simulation can produce all the simulation results. Before the simulation is implemented, the a shortest path calculation is first implemented to fix the prescribed routes for all the habitual travelers. During the simulation process, a shortest path calculation is needed in every certain time intervals to obtain the new routes for those adaptive travelers, and it is finished when every traveler reaches her destination.

2.1.2 Diversion ratio

We here show that the diversion ratio is crucial in determining appropriate queuing patterns and simulation results. Note that NetZone uses LWR kinematic wave model as the underlying traffic flow model. The LWR kinematic wave model considers the physical space a vehicle takes, so queues in this model takes up space and can block traffic from entering a downstream link if space runs out on that link. Moreover, the LWR model describes queue growth in a more realistic way through its shock wave mechanism. Here we adopt the Cell Transmission Model (CTM) implementation of the LWR model for traffic movement on links (Daganzo 1994). For traffic flow through junctions, we use a general node traffic model given in Nie & Zhang (2007). It should be pointed out that node models play an important role in determining queuing spillback.

Suppose there are M approaches at an intersection and those approaches are marked as $1, 2, 3, \dots, M$. Flows leaving any approach will diverge to any other approaches and meanwhile, any approach also serves as a merge point of flow from any other approaches. Therefore, merges and diverges of all the approaches occur simultaneously. Let v_{ij} be the number of vehicles moving from approach i to j during a loading time interval. In order to describe traffic movements through intersections, we first define the demand (supply) of a link at time t , $D(t)$ ($S(t)$), as the maximum number of vehicles that are allowed to leave (enter) the link at t . Assume the vehicle proportion at upstream link i heading for downstream link j , a_{ij} , is known according to the vehicles in the last cell of link i under the LWR model, and demand and supply for each cell is computed based on the fundamental diagram. v_{ij} reads (Nie & Zhang 2007),

$$\begin{aligned} \text{virtual demand } \overline{vd}_i(t) &= \min \left(D_i(t), \min_j \left\{ \frac{S_j(t)}{a_{ij}(t)} \right\} \right) \left(\right. & (2.5) \\ \text{virtual supply } \overline{vs}_i(t) &= \min \left(S_i(t), \sum_j \left(a_{ij}(t) D_j t \right) \right) \left(\right. \\ v_{ij}(t) &= \min \left(\overline{vd}_i(t) a_{ij}(t), \overline{vs}_j(t) \frac{\overline{vd}_i(t) a_{ij}(t)}{\sum_k \overline{vd}_k(t) a_{kj}(t)} \right) \left(\right. \end{aligned}$$

which is a generalization or streamlined version of several node models (Daganzo 1994, 1995, Lebacque 1996, Jin & Zhang 2003, 2004). As a matter of fact, Equation 2.5 does not strictly enforce FIFO at diverge nodes, but since we do not pursue PUE in this paper, the FIFO condition can be relaxed.

Now consider the network of Figure 2.1 (b), where travelers from link 0 heading for the destination can choose either link 1 or link 3 to go through an intermediate node. Link 1 has a lower free-flow travel time than link 3 and it is preferred by travelers under slight congestion. Link 2 serves as a bottleneck due to a lane drop and a queue may grow and back up to both link 1 and link 3. Figure 2.1 (a) gives the fundamental diagram of link 1 with the capacity C_m , free-flow speed u_f and jam density k_j .

Due to the shorter free-flow travel times on link 1 than link 3, habitual travelers will take link 1 rather than link 3. There could be a case that all adaptive travelers also use link 1 regardless of the diversion ratio. To see this, suppose a worst case on link 1 where the outflow rates of link 1 achieves minimum when it equals to the capacity of link 2 (i.e. $C_i = C_{m,2}$) and link 4 is not used, so that the travel speed on link 1 achieves the minimum. Therefore, flow on link 1 is at density k_i and the traversal speed is u_i . Link 3 will never be used if its free-flow

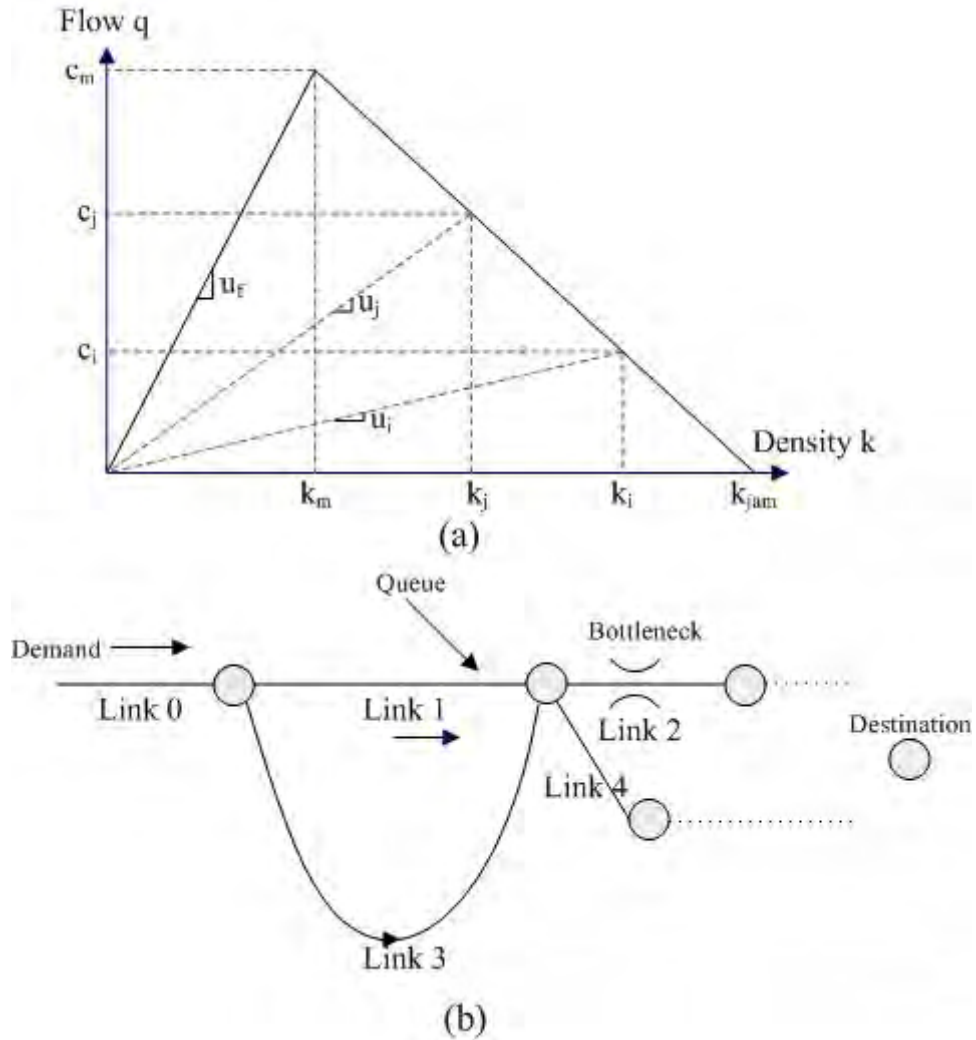


Figure 2.1: (a) The fundamental diagram of link 1; (b) A sample network

travel time is larger than the travel time on link 1, i.e.

$$\frac{l_1}{u_i} < \frac{l_3}{u_{f,3}} \tag{2.6}$$

Therefore, link 1 is over-saturated (i.e. the queue regulates its inflow) and a queue could spillover to upstream links. In this case, the queue may spill back upstream, and this can be unrealistic when link 3 is not that much longer than link 1 and in practice it may be an acceptable choice to some travelers. No diversion ratio can reduce such oversaturation under this setting.

Even though Equation 2.6 does not hold (i.e. link 3 offers relatively competitive free-flow travel time), there is still a case that the queue on link 1 spills over and link 3 is not used, if the diversion ratio is not properly set. If the diversion ratio is low, then most of demands will be loaded on the pre-trip route, i.e. link 0 to link 1 to link 2. It is easy to see that the queue spills

back to link 0 due to the low diversion ratio. On the other hand, if the diversion ratio is high, most travelers are willing to switch to a route with shortest instantaneous travel time. Suppose both links 2 and 4 are used and link 2 is still a bottleneck link. In this case, the outflow rates of link 1 becomes C_j and $C_j > C_i$. Therefore, the instantaneous travel speed on link 1 is now u_j . Link 3 will never be used if its free-flow travel time is larger than the travel time on link 1, i.e.

$$\frac{l_1}{u_j} < \frac{l_3}{u_{f,3}} \quad (2.7)$$

Only if the diversion ratio is in a reasonable range, not too low and not too high, then both links 1 and 3 will be used and the queue on link 1 will not spill over. One can also find other examples to illustrate a similar phenomenon. Therefore, an appropriate diversion ratio is crucial in determining queuing patterns, and should be carefully calibrated in practice.

2.1.3 Hybrid assignment

We usually apply the new route choice model in the traffic simulation for the entire simulation period. However, NetZone users have choices of imposing it only for a certain period. For instance, travelers may be more willing to divert during peak hours than off-peak hours. This is because the congestion is usually more severe and commuters are more likely to choose alternative routes to reach their offices in peak hours, while they may choose prescribed routes during off-peak where merely slight congestion may occur on the roadway. The choice of imposing the new route choice model during certain time periods, also called **hybrid assignment**, is added to NetZone to study the effect of different route choices particularly for a long lane-closure time period. This allows users to specify a peak period within the simulation period. Adaptive travelers are only considered during the peak periods while all travelers are assumed to be habitual travelers for off-peak periods.

2.2 The work zone models

2.2.1 Traffic flow model

A new work zone traffic flow model in NetZone is developed. In the previous version of NetZone, work zone was modeled as a special type of incident occurring at the starting point of a work zone area. As such, an active work zone plan only affects the capacity of the roadway in that work zone area, while the “slow-down” effect caused by work zone is not captured. This deficiency limited the application of NetZone in evaluating a general work zone plan. In the new NetZone, we propose a revised cell-transmission model (CTM) to describe flow propagations through the

entire work zone segment. The revised traffic flow model takes into account not only the capacity reduction under work zones, but also the speed limit reduction.

Before we present our new work zone traffic flow model, we first review the general link model in the context of mesoscopic dynamic traffic simulation that is adopted in NetZone (Nie 2006). Each link, regardless of the presence of a work zone, is divided into three components, an entry boundary (ENB), an exit boundary (EXB) consisting of multiple movements and a traffic propagation section, as shown in Figure 2.2. ENB is a fictitious element that temporarily receives the traffic flow ready to enter the link at the current time. Conversely EXB holds all vehicles that are about to leave the link in the next time step provided the associated node model would allow them to do so. Note that EXB consists of a list of sub elements called movements, each corresponding to a downstream link. Vehicles will be classified upon their arrival at an EXB and sent to the movement corresponding to the next link in their journey. The ENB and EXB are connected by a section where CTM is used to capture realistic flow propagation.

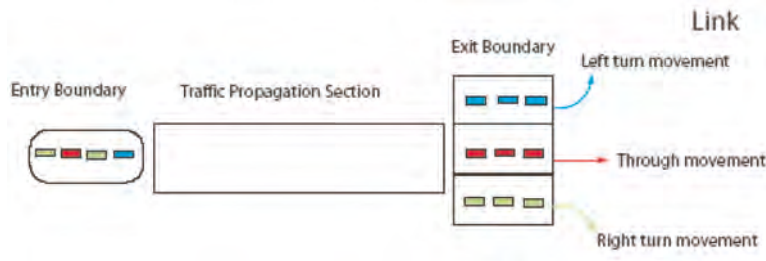


Figure 2.2: Link model in traffic simulation (Nie 2006)

Recall that ϕ_l denotes the length of each time step (i.e. loading time interval). Traffic flow is measured in the unit of *vehicular quantum*. A vehicular quantum is similar to an individual vehicle except that a quantum may carry an arbitrary amount of traffic flow (Nie 2006). Usually we assume that each vehicular quantum should carry the identical amount of traffic, denoted by δ_f . Each link is divided into $L - 1$ cells, with an identical length

$$\delta x = u_f \phi_l \quad (2.8)$$

where u_f is the free-flow speed. The number of cells L is calculated by

$$L = \lceil \text{dist} / \delta x \rceil \quad (2.9)$$

where dist is the link length and $\lceil a \rceil \equiv \text{argmax}\{i < x, i \in Z\}$. The EXB element is also a cell with a length $\delta x_l = \text{dist} - (L - 1)\delta x \geq \delta x$.

Consider a link with a capacity C_0 and free-flow speed u_0 . Its jam density is $k_{jam,0}$, while its density at maximum flow rate is $k_{c,0}$. The maximum backward wave speed is w_0 . With the presence of a work zone, suppose the capacity of the link reduces to C_1 measured by the downstream vehicle discharging rate and the reduced speed limit is u_1 . We assume the maximum backward wave speed does not change, i.e., $w_1 = w_0$. Therefore, the changes in fundamental diagram (FD) for the link are shown in Figure 2.3.

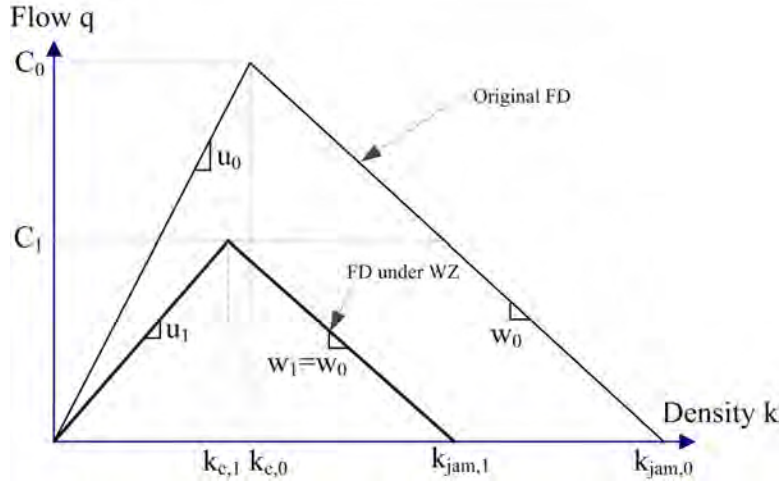


Figure 2.3: Changes in fundamental diagram (FD) with the presence of a work zone

Recall that each link is homogeneous in terms of road properties where no work zone is present. In that case, the FD is known and identical for all the cells. Let l_i denote the number of vehicular quanta in cell i and the density at cell i is given by

$$k_i = \frac{l_i \delta_f}{\delta x} \quad (2.10)$$

Let $F_0(k)$ represent the original FD, i.e. the function of flow rate with respect to the density. For every loading time interval, we update the flux $v_{i,i+1}$ across the boundary between cells i and $i + 1$ using the following supply-demand approach where no work zone exists,

$$v_{i,i+1} = \min\{D_i, S_{i+1}\} \quad (2.11)$$

where D_i and S_{i+1} are demand of cell i and supply of cell $i + 1$ respectively, and

$$D_i = \begin{cases} F(k_i) & \text{if } k_i < k_{c,0} \\ C_0 & \text{if } k_i \geq k_{c,0} \end{cases} \quad S_i = \begin{cases} C_0 & \text{if } k_i < k_{c,0} \\ F(k_i) & \text{if } k_i \geq k_{c,0} \end{cases} \quad (2.12)$$

As we discussed before, when a work zone is activated in a certain segment of the link, the cells within the work zone segment follow a different FD with reduced capacity and/or reduced

free-flow speed, while other cells outside of the work zone segment resemble the same FD as the original one. Therefore, the link becomes inhomogeneous with the presence of work zone. In fact, following Equation 2.8 to determine the cell size (Lebacque 1996), we should re-generate the cells for the work zone segment with a smaller cell size $\delta x = u_1 \phi_l < u_0 \phi_l$. However, changing the cell size and thus the number of cells in the middle of the dynamic network simulation can bring in some computational issues. For instance, the length of the work zone segment is usually not divisible by the new cell size. Whenever some cells are re-generated during the simulation, the vehicular quanta in old cells will be assigned to the new cells; both of which can produce significant computational errors. In addition, it is necessary to store the dynamic changes in the density of each cell, which are used later to retrieve traffic propagation information after the simulation. Changing the cell size could increase the computational complexity substantially. After all, in the case of the presence of work zone, we assume the same cell size as in the case with active work zones. Rather, we revise the formula of boundary flux to capture the work zone effect brought by the FD change.

For every loading time interval, with the presence of work zone, we update the flux $v_{i,i+1}$ across the boundary between cells i and $i + 1$ using the following supply-demand approach,

$$v_{i,i+1} = \min\{D_i, S_{i+1}\} \quad (2.13)$$

where D_i and S_{i+1} are demand of cell i and supply of cell $i + 1$ respectively. If cell i falls outside of the work zone segment, then use Equation 2.12 to determine the cell demand and supply. However, if cell i falls in the work zone segment, then

$$k_i = \frac{\delta f}{\delta x} \left(l_i \frac{u_1}{u_0} \right) \quad (2.14)$$

$$D_i = \begin{cases} F_1(k_i) & \text{if } k_i < k_{c,1} \\ C_1 & \text{if } k_i \geq k_{c,1} \end{cases} \quad S_i = \begin{cases} C_1 & \text{if } k_i < k_{c,1} \\ F_1(k_i) & \text{if } k_i \geq k_{c,1} \end{cases} \quad (2.15)$$

k_i in Equation 2.14 indicates the equivalent density of cell i with the length of $u_0 \phi_1$ under the new FD (i.e. F_1 function).

2.2.2 The case of full closure

The old work zone model is incapable of modeling the case where a roadway section is fully closed in certain time periods. In the new work zone model, we implement a work zone with full closure into the route choice model.

Recall that travelers are categorized into two groups, habitual travelers and adaptive travelers. When those work zone segments are fully closed during a time period in the middle

of the dynamic network simulation, those links are temporarily removed from the network. Adaptive travelers choose their routes from the temporary network at every loading time interval until the work zone is completed and those links are open again. As for habitual travelers, they strictly follow prescribed paths and do not change during the trip. We generate prescribed path sets for those habitual travelers whose departure time is later than $\Gamma_1 - \Omega$ but earlier than $\Gamma_2 - \Omega$ using the K-shortest paths based on the temporary network, i.e. the network with all the work zone links removed. Γ_1 and Γ_2 is the full closure starting time and ending time, respectively. Ω is the estimated average travel time from the origins to the full closure segment (e.g., 15 minutes). For those habitual travelers whose departure time is later than $\Gamma_2 - \Omega$, their prescribed paths are still based on the full network, the same as the travelers departing earlier than $\Gamma_1 - \Omega$.

In reality, it is rather difficult to determine the real prescribed paths of those habitual travelers whose departure time is around the full closure starting/ending time, as they may or may not intend to take those work zone segments, depending on their estimated travel time to the work zone or other travel behavioral factors. However, a uniform yet reasonably large Ω for all travelers may lead to minimal errors in the sense that those habitual travelers do not have real traffic information, and within the work zone analysis time periods, they tend to travel conservatively to avoid those fully closed links. In addition, when several links in the network are fully closed, the diversion ratio is usually high and could be close to 1. Therefore, the total number of habitual travelers is usually small in that case. In other words, the majority of the travelers are willing to divert and thus only very few travelers remain to follow their prescribed paths. This can also reduce the computational error resulted from this assumption.

Another way to overcome this shortcoming with the full closure work zone is to set the analysis time horizon to be exactly the time period of full closure. This can eliminate any possible errors caused by assuming a restricted prescribed path sets for habitual travelers. If a longer analysis time horizon is necessary, then it would be ideal to create three scenarios, during the full closure, prior and posterior to the closure, and finally add up the results of all three scenarios.

2.2.3 Cumulative curves and travel times

We improved the method of computing instantaneous travel times based on the results of dynamic network simulation, which is less likely to lead the simulation to the gridlock.

Recall that link cumulative curves are constructed after the simulation is performed. Link traversal times and path travel times are retrieved from link cumulative curves as shown in Figure 2.4. Each assignment time interval is divided into several loading intervals in the need of

a higher resolution (an assignment time interval must be a multiple of a loading interval), and the duration of the loading interval is denoted by φ_l . Given a path flow pattern \mathbf{f} , the simulation stores the number of vehicles arriving and departing each link, μ^t and v^t , at each loading time interval t . In the original model, we obtain the travel time of any vehicle entering a link at time t by,

$$\tau^t = \operatorname{argmin}_k \{ \mathbb{A}(t) \leq \mathbb{D}(k) \} - t \quad (2.16)$$

where $\mathbb{D}(t)$ and $\mathbb{A}(t)$ are the cumulative number of vehicles arriving and departing a link, respectively. τ^t is then rounded up to the nearest integer. Thus, the path travel time w_{pt}^{rs} can be obtained by recursively summing up the traversal times of all the link along path p .

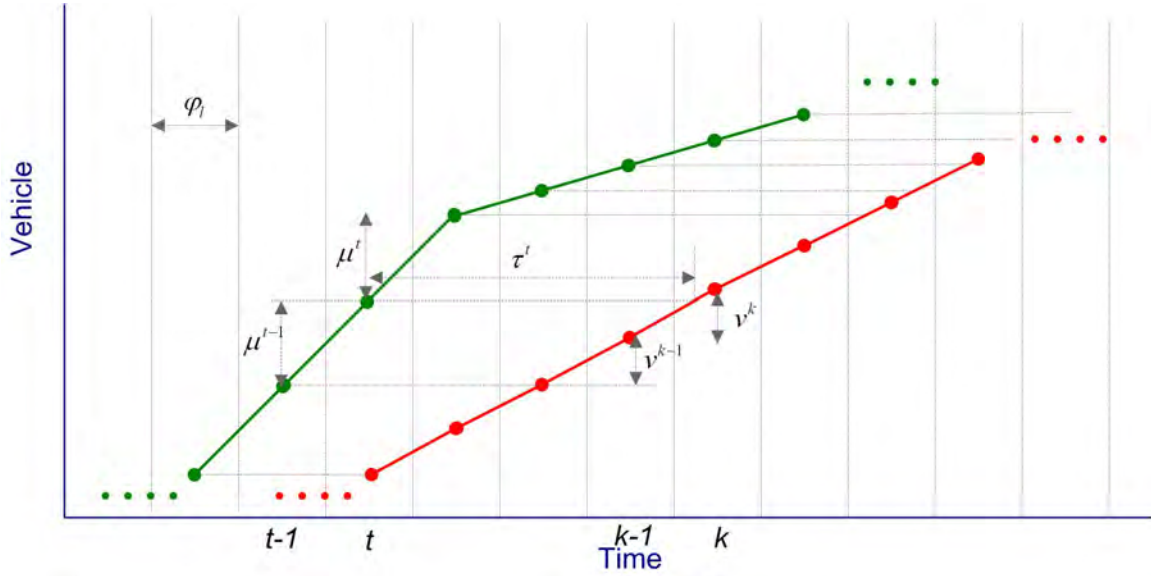


Figure 2.4: A link cumulative curve obtained from traffic simulation

In the new version of NetZone, we revised the travel time of a vehicle entering a link at time t to be,

$$\tau^t = \operatorname{argmin}_k \left\{ \mathbb{A}(t) < \frac{\mathbb{D}(k) + \mathbb{D}(k+1)}{2} \right\} - t - 1 \quad (2.17)$$

Compared to the original method of computing travel times, this new method tends to round down travel times to the nearest integer (in the unit of loading intervals) rather than rounding up. Our numerical studies in both medium-scale and large-scale networks imply that the new method can significantly reduce the possibility of falling into gridlock and meanwhile is more likely to produce realistic simulation results than the original method.

2.2.4 Traffic diversion model

We improved the method of computing no show rate (NSR) in the traffic diversion model. Recall that demand diversion during the work zone comprises two parts: trip cancelation or modal shift (i.e., no show) and diversion to alternate routes. The no show rate indicates the reduction in the demand and this component is central to the dynamic traffic simulation. In the previous version of NetZone, we have already created a framework to compute traffic diversions where the effects of a few factors to the network performance are taken into account. These factors include anticipated traffic delay caused by the work zone, traffic management measures (pre-trip traveler information, media campaign, highway advisory radio and variable message signs) and work zone characteristics (weekday/weekend project, daytime/night project). The no show rate was determined by these factors altogether and then applied to the demand of all the O-D pairs.

It is reasonable to assume that all the trips in the network are affected equally by pre-trip traveler information, media campaign, highway advisory radio and variable message signs, since those traffic management measures are open to all the travelers. However, the anticipated traffic delay caused by the work zone could vary substantially among travelers. Apparently, travelers taking the routes through work zone area are more likely to cancel their trip, shift to the transit, or take other alternative routes than those taking the routes far from the work zone. Therefore, a uniform no show rate applied to all the trips may be far unrealistic.

We established the model of no show rates for each O-D pair in the new NetZone in the way that OD-specific no show rates are calibrated first and then are used towards the simulation. The model is as follows,

$$NSR_{rs} = \begin{cases} 0 & DR_{rs} \in (-\infty, 0) \\ 1 - a_1^{DR_{rs}} & DR_{rs} \in [0, 0.02] \\ 1 - a_1^{DR_{rs}} a_2^{TIS} a_3^{Campaign} a_4^{Night} a_5^{Weekend} & DR_{rs} \in (0.02, +\infty) \end{cases} \quad (2.18)$$

where NSR_{rs} stands for the no show rate for O-D pair rs . DR_{rs} is the delay reduction ratio for O-D pair rs ,

$$DR_{rs} = \frac{D_{ws}^{rs} - D_b^{rs}}{D_b^{rs}} \quad (2.19)$$

where D_{ws}^{rs} is the total delay of all the trip between O-D pair rs with the presence of the work zone and not considering demand reduction. D_b^{rs} is the total delay of all the trip between O-D pair rs without work zone construction.

TIS , $Campaign$, $Night$, $Weekend$ are binary variables characterizing factors affecting the travel demand. More specifically,

$TIS = 1$ if a pre-trip traveler information system is applied, $TIS = 0$ otherwise;

$Campaign = 1$ if a media campaign is performed and $Campaign = 0$ otherwise;

$Night = 1$ if the project is performed during the night (9:00 pm - 5:00 am) and $Night = 0$ otherwise;

$Weekend = 1$ if the project is performed during weekends and $Weekend = 0$ otherwise.

$a_1 \in (0, 1]$ is a user specified parameter characterizing the demand reduction due to the increase in the total delay. Namely, suppose there are no traffic management measures and the work zone project is a daytime, weekday project, the demand during construction will be a_1^{DR} of the original demand (for $DR \geq 0$). The higher the increase in delay, the greater demand reduction during construction. $a_2, a_3, a_4, a_5 \in (0, 1]$ are user specified parameters corresponding to the factors or attributes that induce demand reduction. Namely, a_2 corresponds to *TIS*, a_3 to *Campaign*, a_4 to *Night* and a_5 to *Weekend*. For example, $a_2 = 0.9$ means that the application of pre-trip traveler information will reduce the total demand to 90% of the original demand. In addition, we assume that these factors will have effects on the travel demand only when $DR \geq 0.02$. The parameters a_1, a_2, a_3, a_4, a_5 require to be specified by users based on past experience. If no additional data are available, we suggest users to use 0.95 for all the parameters.

2.3 Origin-Destination connectors

In network modeling, it is customary to use centroid nodes to represent traffic analysis zones (TAZ), from/to which trips are assumed to have originated (Origins) or destined (Destinations). In the previous version of *NetZone*, each centroid was connected to the network with one connector. Such an O-D connector model has several issues. First, it may lead to mis-calibration and mis-prediction. For instance, those links that are directly connected to the centroid connector for each origin/destination may be loaded intensively, which produces artificial congestion. This clearly distorts the simulation results. In reality, trip origins and destinations are much more distributed and can scatter throughout a TAZ. Second, this model may be accurate only if all the TAZs are sufficiently small to cover several roadway segments and intersections. However, it is difficult to obtain very refined dynamic O-D trip tables and this is not computationally plausible for large-scale networks.

Therefore, it is necessary to connect origin/destination nodes to the network using multiple centroid connectors to reduce any possible artificial congestion and reduce computation complexity. A typical centroid in a urban network with four connectors is shown in Figure 2.5. It is preferred that connecting nodes are those where the real traffic is heavily released to the

network if any such information can be obtained. If no information regarding vehicle release locations is known or the traffic demand is evenly distributed within the TAZ, then it is suggested that the centroid is connected to those nodes that are scattered evenly.

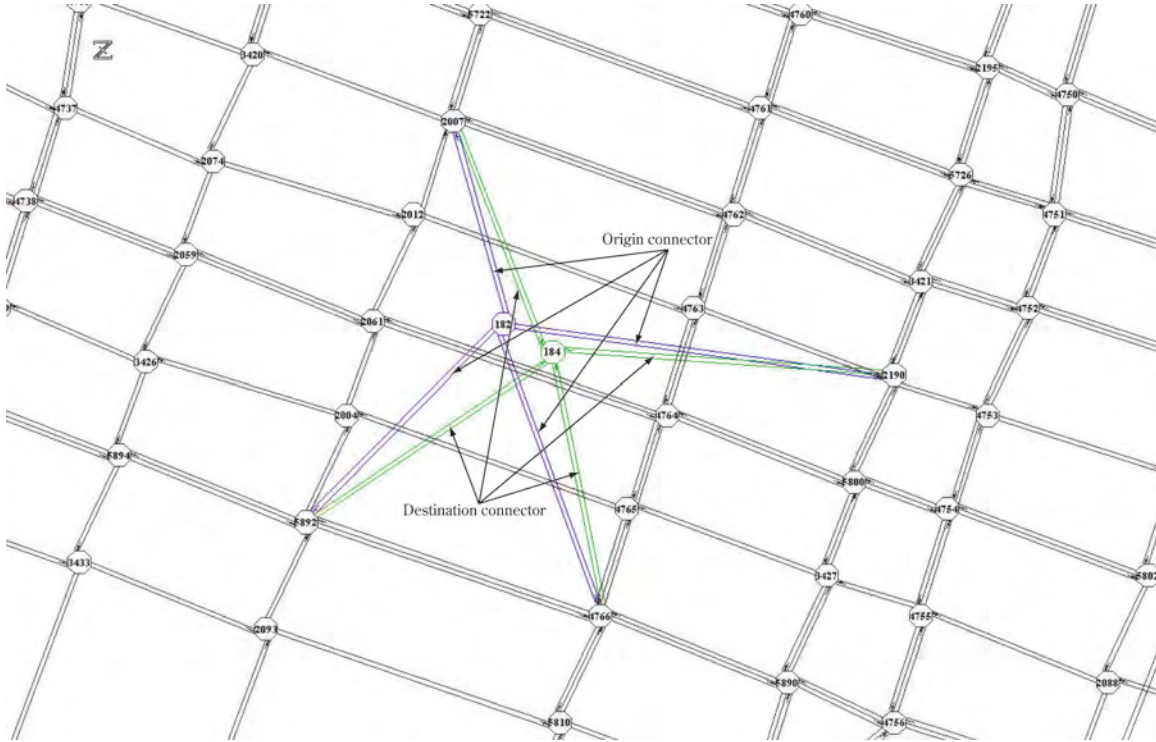


Figure 2.5: Origin/destination node and connectors

Recall that in the previous *NetZone*, each origin (destination) node is marked with type “DMOND” (“DMDND”) and its connector with type “DMOLK” (“DMDLK”). Please see our report (Zhang et al. 2007) for detailed description of those link/node models. We made three major modifications to improve the O-D connector model, and the new model is shown in Figure 2.6.

- An intermediate node is attached to each origin node and connected by an intermediate connector. The intermediate node and connector resemble the old O-D connector model. Further, the intermediate node is connected to arbitrary number of regular nodes by connectors. Those connectors are assigned with Point-queuing traffic flow models (i.e. the type “PQULK”, also see our report for details) with infinite capacity and zero travel time. The same logic also applies to each destination node.
- Because the intermediate node does not have physical meanings and is only used to accommodate underlying models, it may confuse *NetZone* users to some extent. We let the

thus encourage travelers to carpool, which in some cases can reduce the congestion. Therefore, it may not be realistic to omit those HOV lanes when evaluating the work zone impact to the network. We here add a model to the NetZone to analyze the HOV traffic on HOV facilities. Before presenting our HOV model, we suppose that the time dependent O-D demands for both HOVs and single-occupant vehicles (SOV) are known (input by users) prior to performing the simulation.

Consider a freeway segment with HOV lanes in a corridor network as shown in Figure 2.7(a). We construct a new network where the mainlines of the freeway segment are divided into two parts, HOV links and general-purpose (GP) links. The HOV lanes are assumed to be separate links paralleled to the freeway GP lanes. Traffic in the GP links and HOV links interacts only at certain locations as shown in Figure 2.7(b). Those interaction locations can be modeled in bi-directional links or nodes. All the HOVs can fully access the entire new network, while the SOVs can only access a subnetwork, i.e. the roadway facility excluding HOV links and those access links/nodes. Therefore, the network simulation considering HOVs and SOVs are essentially the network loading problem with two groups of travelers, each of which has its own accessible network. We revised the underlying CTM-based traffic flow model as follows.

If those locations where GP links and HOV links intersect are modeled by bi-directional links, then the freeway segment is represented by cells shown in Figure 2.7(c). At each of those interaction locations, HOVs in the upstream cell of the HOV (GP) lane can choose to either continue to take the HOV (GP) lane by entering the downstream cell of the HOV (GP) lane, or switch to the GP (HOV) lane by entering the interactive cell. In each loading time interval, the interaction area is essentially modeled by “two junctions”, each of which has two incoming cells and two outgoing cells. On the other hand, if those interactive locations are modeled by interactive nodes, then the freeway segment is represented by cells shown in Figure 2.7(d). Vehicle merge and diverge occur simultaneously at those locations. HOVs from the two upstream cells, one of HOV links and the other of GP links, enter the two downstream cells, depending on their route choices. The interaction area is essentially modeled by “one junction” for HOV. In both cases, SOVs cannot access those HOV lanes, and they always enter the downstream cell of the GP links from the upstream GP cell.

Modeling interaction locations by “two junctions” assumes two cells connecting the HOV links and GP links, and any HOVs entering HOV lanes or exiting will stay at least one loading time interval at those interactive cells. A significant number of HOVs changing lanes may cause a queue at those interactive cells and thus can lead to congestion on upstream cells in both

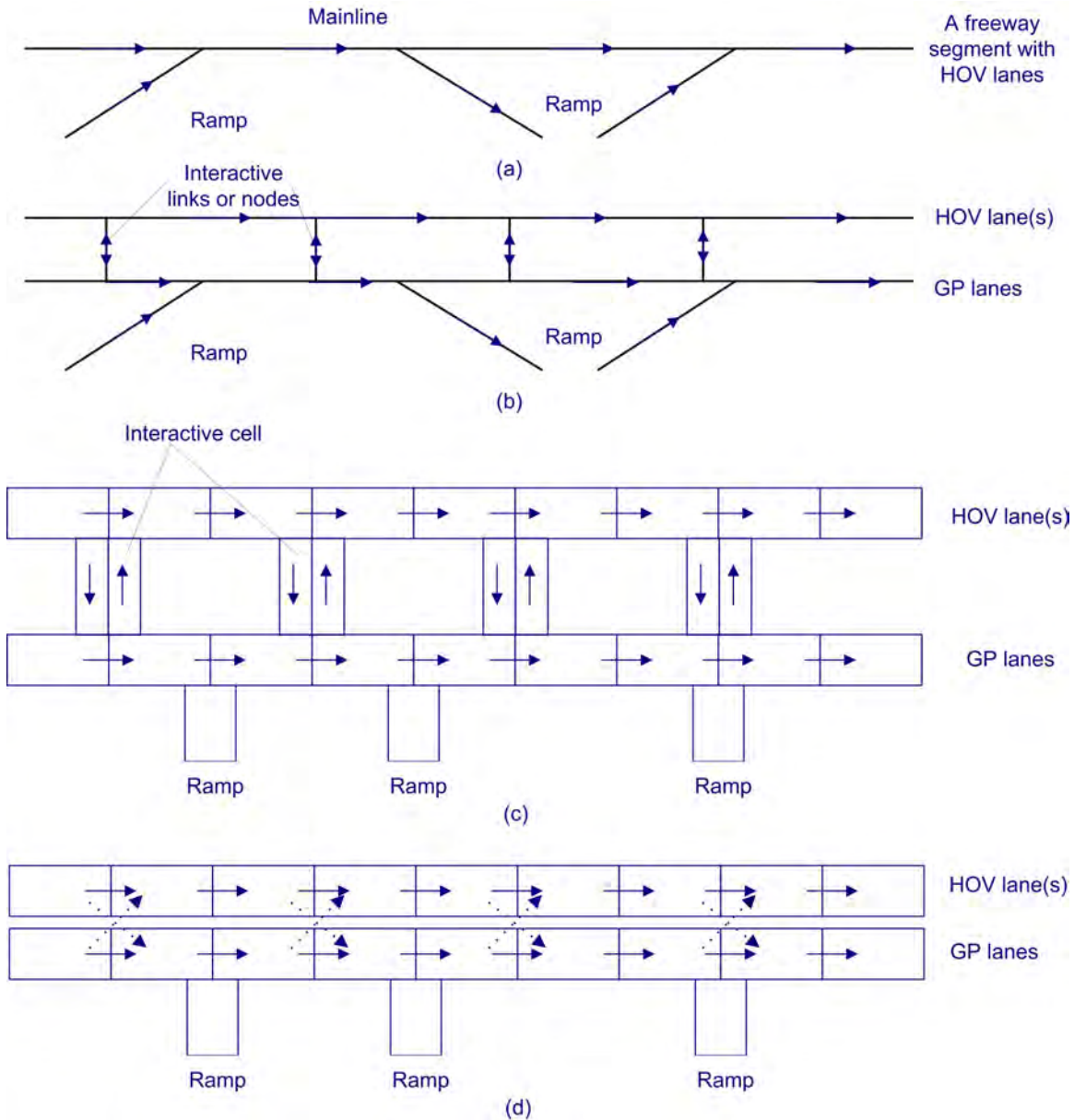


Figure 2.7: Demonstration of the new High-Occupancy Vehicle (HOV) model

HOV links and GP lines. However, there is no such additional “synthetic” travel time for changing lanes if interaction locations are modeled by “one junction”. HOVs can enter or exit the HOV lanes freely if no queue exists in the downstream cells. Overall, the former model is more suitable for the case where GP lanes are in severe congestion and HOVs have significant impact to the traffic flow by entering or exiting HOV lanes, while the latter model may be realistic in the case where either there is only one GP lane and one HOV lane or GP links are not congested. Users can connect HOV links and GP links by either two-way links or a node,

dependent on which model they choose.

Given the revised CTM-based traffic flow model, we now are ready to present the routing choice model for both HOVs and SOVs in the analysis time period. HOV lanes are usually activated during certain time periods (for instance 6:00am to 10:00am), which is typically a time interval within the entire analysis time period. The HOV time period, analysis starting time and ending time are shown in Figure 2.8. HOVs can fully access the entire network including HOV lanes. Therefore, habitual HOVs follows their pre-scribed routes which are selected from the entire network, while adaptive HOVs will choose the shortest paths in response to the current traffic condition of the entire network. In the beginning of the analysis time period (or at the end of it), SOVs select the routes in the same way as HOVs because HOV lanes are not activated. However, SOVs are restricted to a subnetwork (excluding all the HOV lanes) during the HOV time period. In that case, habitual SOVs who take the freeway segment with HOV lane activated will change their prescribed routes based on the subnetwork before the HOV time period starts. When the HOV time period ends, they can again access the entire network and still use the same prescribed routes as HOVs. Because it takes some time for SOVs from departure to arrival to the freeway segment with HOV lane activated, habitual SOVs will reroute at their departure which is usually a few minutes earlier than the HOV starting time. Similarly, they start to use their original prescribed routes again at a departure time a few minutes earlier than the HOV ending time. The two critical departure times are called “SOV rerouting time” and marked as 5:45am and 9:45am in Figure 2.8. In real cases, users should choose proper starting time of SOV rerouting, because if it is too early, then the traffic flow on the HOV links may be greatly underestimated when the HOV is not activated; If it is too close to the starting/ending time of HOV time period, then there may be significant violations for SOVs, i.e. a number of SOVs assigned to the HOV lanes during the HOV time period. Similarly, the ending time of SOV rerouting should also be chosen properly so that the flow on the HOV lanes can be appropriately estimated with minimal SOV violations.

The implementation procedure of the dynamic network simulation with the presence of HOV lanes is as follows,

DYNAMIC SIMULATION PROCEDURE WITH HOV LANES

Step0 Initialization.

Set $t = 0$. Assume an initial network state. Generate prescribed route sets based on the entire network for all the habitual travelers

Step1 Assignment.

If t is smaller than the starting time of HOV time period, or larger than its ending time,

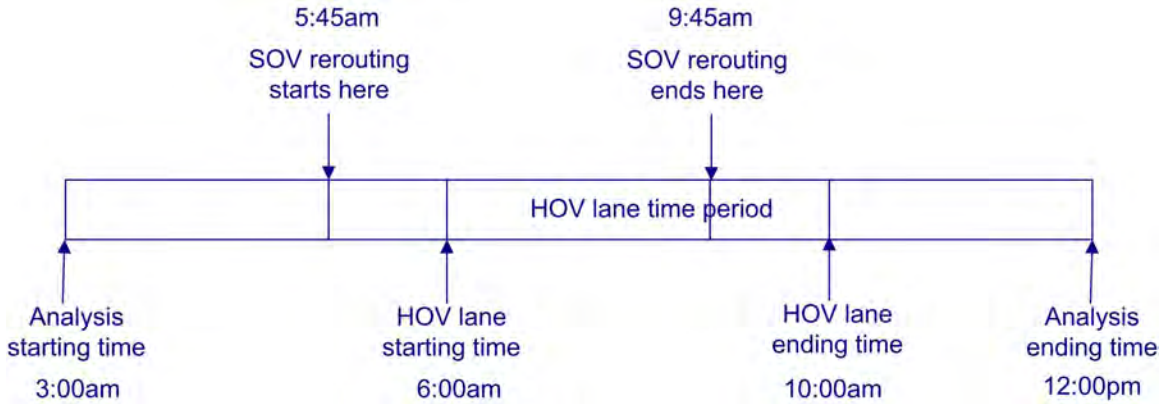


Figure 2.8: HOV time period in the analysis time period

then for each node r leading to destination s , compute the current shortest paths for all the adaptive travelers from r to s based on the current state of the entire network; otherwise compute the shortest paths based on the entire network only for adaptive HOVs, and do it for adaptive SOVs based on the subnetwork excluding HOV links.

If t is larger than the starting time of SOV rerouting and smaller than its ending time, regenerate the prescribed route sets for habitual SOVs based on the subnetwork excluding HOV links.

Suppose link (r, j) lies on the shortest path from r to s . Load all the adaptive travelers at node r heading for destination s at time t onto link (r, j) . Update the network state.

Step2 Set $t = t + 1$ and go back to Step 1 till the loading horizon is over.

We have modeled two groups of travelers in dynamic network simulation. One group, HOVs, has fully access to the entire network, while the other group, SOVs, can only access a subnetwork during a certain time period. The above method, in fact, can be used to model traveler heterogeneity in a more general sense that each group of travelers can access only a subset of the network during a certain time period. For example, suppose we model three groups of travelers, cars, buses and trucks. Cars can access the entire network without any time restrictions. Buses can only use certain network links and have pre-determined schedules. In addition, trucks are restricted to access some links of the network in peak hours. This HOV model can be easily extended to model such traveler heterogeneity, which could be one of our focus in the future research on NetZone.

Chapter 3

Traffic control

It is important to incorporate the traffic signal control in dynamic network simulation. The traffic signal control component in **NetZone** has been re-organized and further expanded to accommodate more traffic control options and strategies. The previous version of **NetZone** only supports several basic control strategies, i.e. pre-timed signal control at isolated intersections and ALINEA algorithm for ramp metering at freeway junctions. In addition to those, the new **NetZone** now provides vehicle actuated control, stop-sign and yield-sign controls at intersections, signal coordinations between adjacent intersections/ramps, pre-timed ramp metering and traffic signal schemes by time of day. Those options and strategies of traffic control contribute to a more realistic simulation model in the context of dynamic networks.

In this chapter, we describe in details the implementation of traffic signal control in **NetZone**. We first briefly present the traffic signal control model embedded in CTM-based traffic flow models. **NetZone** relies on specific files regarding signal timing schemes to perform simulations with signal control, and those files can either be prepared manually by users or generated automatically by the build-in GUI. We then discuss the formats of input files of signal control for both intersections and ramp metering. Finally we show how to use GUI to perform simulation with signal control.

3.1 Traffic control in CTM models

Traffic control is incorporated in the underlying traffic flow model, i.e. CTM models. There are two types of traffic control, traffic signal control where vehicles are allowed to move through an intersection or a ramp only at green time, and traffic sign control (or priority control, for instance, stop sign and yield sign). The two types are modeled differently in **NetZone**.

3.1.1 Signal control

Recall that we define the demand (supply) of a link at time t , $D(t)$ ($S(t)$), as the maximum number of vehicles that are allowed to leave (enter) the link at t . The demand and supply for each cell is computed by Equation 2.5 based on the fundamental diagram and the current vehicle queue maintained at each cell, and then are used to update the flow propagation.

Ramps with signal control can also be modeled by this supply-demand approach. We only need to revise the formula of the upstream demands taken into account control schemes. For a freeway on-ramp with a meter, for example, the demand of the upstream ramp cell is computed by

$$D(t) = \min\{rC, Q(t)\} \quad (3.1)$$

where C is the flow capacity of the link and $Q(t)$ is the flow ready to exit the link at time t . $0 \leq r \leq 1$ is the metering rate which may be set based on any metering algorithm.

For a general intersection with signals, we apply the same supply-demand approach for each movement. The movement here is defined as a directional descriptor from a specific EXB cell at the end of the preceding link to the first cell of the successive link. Because each EXB cell has a targeted successive link, the vehicles moving from EXB cells do not diverge. In addition, with proper signal phase schemes, the movements in each phase have no conflict points and the share of the downstream link is minimal between these movements. Therefore, the node model by Equation 2.5, as a matter of fact, be simplified as the following for those movements that are given the right-of-way at each loading time interval. In applying the supply-demand approach for each of those movements, merely one upstream cell (EXB cell) and one downstream cell are considered.

$$\text{For any movement from } i \text{ to } j, \quad v_{ij}(t) = \min(C_j, D_{ij,EXB}(t), S_j(t)) \quad (3.2)$$

where C_j is the capacity of link j and $D_{ij,EXB}(t)$ the demand of the EXB cell on link i heading for link j at time t .

3.1.2 Priority control: stop sign and yield sign

Stop sign control operates on a “first-come-first-serve” basis, and thus it is crucial to maintain an order of vehicle arrivals from each approach. Ma (2008) gives a method to incorporate stop sign control in the CTM model. Suppose an all-way stop sign intersection has L incoming links, $i \in 1, 2, \dots, L$. $ROW_i(t) = k$ represents that the incoming link i (also called approach) ranks k -th in the right-of-way order at time t . In other words, vehicles from approach i have the k -th

highest priority to go at time t . Therefore, at each loading time interval, the approach with the lowest $ROW(t)$ will be given the right-of-way. For all-way stop sign control, instead of using Equation 2.5 to update the flow, we update ROW for all the approaches at each time step and only update the flow for the approach given the right-of-way.

Denote d_{ij} as the demand from incoming link i to outgoing link j . The procedure of updating ROW and the flow is as follows (Ma 2008),

UPDATE ROW IN STOP SIGN CONTROL

Step0 Initialization. $ROW_i(0) = \infty, \forall i$

Step1 Set $t = t + 1$ and go to Step 2 till the loading horizon is over.

Step2 Update ROW and determine an approach, denoted by I , to give the right-of-way.

Iterate through $i \in \{1, 2, \dots, L\}$

$$\begin{aligned} ROW_i(t) &= L && \text{if } ROW_i(t-1) = 0 \\ ROW_i(t) &= L && \text{if } \sum_j d_{ij} = 0 \\ ROW_i(t) &= ROW_i(t-1) - 1 && \text{if } \sum_j d_{ij} > 0 \end{aligned}$$

Find I such that $I(t) = \operatorname{argmin}_i \{ROW_i(t)\}$, and let $ROW_I(t) = 0$. Go back to Step 1.

As for yield sign control, it is essentially the case of merge at nodes restricted by priority rules for the approach yielding to others. With yield signs, we first compute the flow between those cells excluding the yielding cell, and finally the vehicles in the yielding cell will only be able to take the remainder of the available space at the downstream cell.

3.2 Overview of signal control implementation in NetZone

Traffic control in NetZone is an add-on function to the NetZone simulation model. With no control scheme defined in the network, the dynamic simulation can still run in NetZone (of course no effects of traffic control to the network are considered). To perform a simulation with signal control, certain files containing information of signal timing schemes must be provided and placed in the same folder as the NetZone network files, and those control files can either be prepared manually by users following certain format or generated automatically by the build-in GUI.

As for the loading order of NetZone files, NetZone first reads all the required network files, construct the network and finally loads the control files if provided any. The order of the required

network files being loaded to NetZone is the network parameter file (*.net* extension), node file (*.nod* extension), link file (*.lin* extension), demand file (*.odp* extension for static demand and/or *.dmd* extension for dynamic demand) and optionally the file regarding assignment patterns (*.asn* extension) and path specifications (*.pth* extension). After all the above information are loaded, the network is ready to be initialized. In this process of initialization, one of the essential step is to establish the node-link connections and their topological relations, including the turning types (right turn, through, left turn or U-turn). After it, the network can load the control files and initialize the signalized intersections and freeway merging junctions.

NetZone implements two levels of control strategies, basic and advanced. Currently, basic strategies include modeling signalized intersections and metered ramp merges for a certain time period. Advanced control refers to control plans in multiple time periods (by time of day, for instance) and local synchronization control (LSC).

3.3 Input file for intersection control

Any information regarding intersection control schemes is provided to NetZone by a file with *.ctl* extension. Four types of intersection control can be modeled and specified, namely pre-timed signal control, vehicle actuated control, stop sign control and yield sign control. All these types share the same file format for defining movements and phases, while they differs in defining other featured parameters. The intersection control file has two formats, one with comment text and numbers and the other contains only numbers defining the control schemes.

The first line of the *.ctl* file gives the number of nodes under traffic control, which then followed by that amount of blocks and each block defines the control schemes for each node. For instance, the first line reads “ControlledNodes 4” (in the format of comment text and numbers) or “4” (in the format of only numbers) indicating that there are four intersections with traffic control. It is then followed by four blocks defining the control schemes for each of the four intersections.

Each of the blocks, regardless of the types of control strategy, starts with the line indicating the node ID number. It then defines the movements, phases, and finally the parameters associated with the specific control strategy. The following subsections describe the format in details.

3.3.1 Movement, phase and control type

Movement serves as a directional descriptor. Starting from the second line of the block defining node control information, the number of movements is first given, then followed by line-by-line specifications of each movement. For example, consider an intersection, labeled as “Node 2” in Figure 3.1 with four incoming links and four outgoing links. Figure 3.2 gives the block of input *.ctl* file defining the control scheme at Node 2, where the left column is accompanied with comment text and numbers and the right column contains only numbers. Node 2 has 12 movements, as defined by the first line of the red sub-block in Figure 3.2. Each movement is given a unique movement ID within this node block, and is specified using the upstream node ID number and downstream node ID number. Note that here we omit the U-turn movements for simplicity.

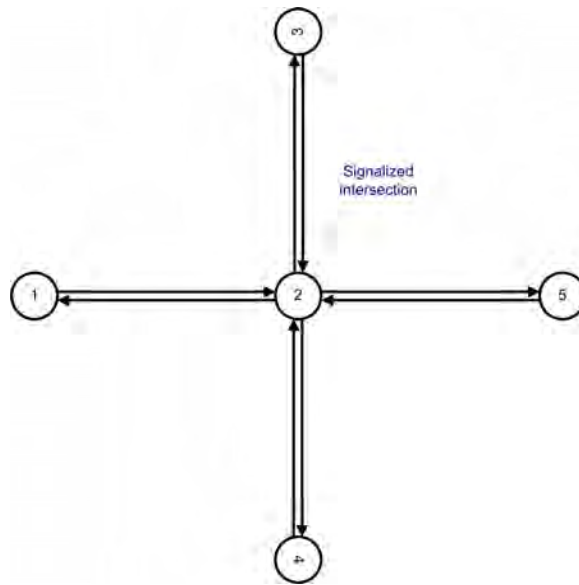


Figure 3.1: An intersection with four incoming links and four outgoing links

Phase is the stage of a movement or a combination of movements that receive the right of way simultaneously during a cycle. After we define the movements, it is necessary to group movements into phases. Following the sub-block of the movement, the phase sub-block starts with the line indicating the number of phases. Thereafter, each phase is specified with a list of IDs of those movements included in the phase. For the same example, phase sub-block is shown in Figure 3.2 in green. Each phase is also given a unique phase ID number. Phase NO. 1 has three movements, including movements ID number 1, 2 and 3.

One important feature of NetZone is that, if the *.ctl* file is generated by build-in GUI,

```

2
12
1 1 4
2 1 5
3 1 3
4 3 1
5 3 4
6 3 5
7 5 3
8 5 1
9 5 4
10 4 5
11 4 3
12 4 1

4
1 3 1 2 3
2 3 1 2 8
3 3 10 11 12
4 3 4 5 6

44
12 9 6 17
9

node 2
movements 12
movement 1 fromnode 1 tonode 4
movement 2 fromnode 1 tonode 5
movement 3 fromnode 1 tonode 3
movement 4 fromnode 3 tonode 1
movement 5 fromnode 3 tonode 4
movement 6 fromnode 3 tonode 5
movement 7 fromnode 5 tonode 3
movement 8 fromnode 5 tonode 1
movement 9 fromnode 5 tonode 4
movement 10 fromnode 4 tonode 5
movement 11 fromnode 4 tonode 3
movement 12 fromnode 4 tonode 1

phases 4
phase 1 movements 3 1 2 3
phase 2 movements 3 1 2 8
phase 3 movements 3 10 11 12
phase 4 movements 3 4 5 6

Cycle: 44
Greensplit: 12 9 6 17
Offset 9
    
```

Figure 3.2: The block in a .ctl file defining the control scheme in Node 2

all the possible movements for each controlled node are generated and defined. NetZone can further analyze the relationship between those movements and phase definition. If any pre-defined movement is not included in any of the phases, then this movement will be automatically marked as a **prohibited** movement. All the prohibited movements are input to route choice models to ensure that no prohibited movement can be a part of the selected routes for any travelers.

The third sub-block following the phase sub-block is reserved for specifying featured parameters for a certain type of control scheme. For example, Figure 3.2 defines a pre-timed signal scheme for Node 2. The control type of each of the control node must be specified in the .nod file loaded to NetZone previously. In the .nod file, “CTLPT”, “CTLAD” and “CTLSN” represents pre-timed signal control, vehicle actuated control and priority control (stop sign control and yield sign control), respectively, as being distinct from regular nodes labeled with “FWJCT”.

3.3.2 Pre-timed signal control

It is necessary to specify the cycle length, green split (i.e. the effective green time for each of the phases) and offset for the node with pre-timed signal control. Such information must be placed after the sub-block of the phase definition. One example is shown in the Figure 3.2. Node 2 has a cycle length of 44 seconds, where the effective green time assigned for each of the four phases 12, 9, 6 and 17 seconds, respectively.

The offset is defined as the start of green time for the first phase relative to the starting time of the network simulation. In the example, the first phase of Node 2 will start 9 seconds later in reference to the network simulation starting time.

3.3.3 Vehicle actuated signal control

The format for defining movements and phases in vehicle actuated signal control is the same as pre-timed signal control. However, its featured parameters, minimum green time and maximum green time, are different and must be placed after the phase definition. For simplicity, we assume the sensors used to detect vehicle arrivals are deployed at the last cell of incoming links and the extended green time is always the duration of a loading time interval (usually a couple of seconds). An example of a block in a *.ctl* file defining vehicle actuated control is shown in Figure 3.3. Node 36 is under vehicle actuated control and has four movements and two phases. The minimum and maximum green time for phase 1 is 8 seconds and 28 seconds, respectively. The minimum and maximum green time for phase 2 is 10 seconds and 36 seconds, respectively.

<pre> 36 4 1 6 94 2 534 94 3 94 136 4 534 136 2 1 3 1 2 3 2 2 4 2 8 28 10 36 </pre>	<p>Min/max green time</p>	<pre> node 36 movements 4 movement 1 fromnode 6 tonode 94 movement 2 fromnode 534 tonode 94 movement 3 fromnode 94 tonode 136 movement 4 fromnode 534 tonode 136 phases 2 phase 1 movements 3 1 2 3 phase 2 movements 2 4 2 minimum/maximum Green Time: 8 28 minimum/maximum Green Time: 10 36 </pre>
---	--------------------------------------	---

Figure 3.3: The block in a *.ctl* file defining vehicle actuated control

3.3.4 Priority control: stop sign and yield sign

Priority control in *.ctl* file is defined similarly to other control types, and it comes with the same format for defining movements as others. However, it does not need to define phases. Two types of priority rules are programmed in NetZone, “all-way” stop sign or “yield” sign. Table 3.1 gives an example of two nodes with priority control.

All-way stop sign must be specified in the key word “ALLWAY” following the movement definition, and so is the yield sign using “YIELD” as the key word. For example, Node 2 is controlled by an all-way stop sign, and 0 after the key word “ALLWAY” is for verification and cannot be omitted. For Node 3, two movements, namely movement 1 and movement 7, will yield to two other movements each. Line “YIELD 2” first specifies the key word “YIELD” and then the number of yielding movements. The next two lines specify the yielded movements. In this case, movement 1 yields to two movements, 6 and 9, movement 7 yields to two movements, 3 and 11. Note that Table 3.1 defines control information using comment text, one can also remove all the comments and use only numbers to code the *.ctl* file.

3.4 Input file for ramp metering control

Ramp metering is defined in a separate file (with *.rmp* extension) in addition to the intersection control file (with *.ctl* extension). Currently, two types of ramp meters can be modeled, i.e., time-of-day pre-timed metering and ALINEA method. The *.rmp* file starts with the specification of the total number of ramp meters in the network, then followed by that amount of blocks each of which defines the control schemes for one ramp meter (i.e. merge point). Unlike the *.ctl* file, the comment text in the *.rmp* file **MUST** be used so that NetZone can read those key numbers properly. However, the words of comment text being used can be arbitrary, as long as they are separated by space as required. Table 3.2 given an example of *.rmp* file where one pre-timed meter and one ALINEA type meter are defined.

The second line (“2.0” in the example) defines the critical occupancy for ALINEA metering strategy. If no ALINEA type ramp meters is defined, then simply input “0” here. Traffic flow detection is modeled based on a single cell, dependent on the location of the detection. NetZone uses simplified triangular fundamental diagram to model the traffic flow, the critical density is the density corresponding to the capacity flow rate. For ALINEA ramp metering, the critical occupancy of the targeted link could be different from the critical density (occupancy) specified by the fundamental diagram of the targeted link. This factor is the multiplier to convert the critical density to the parameter (k_o) required by ALINEA algorithm. For example, if the target

Table 3.1: Sample Signal File Format: Priority Control

```

ControlledNodes: 2
node 2
movements 7
movement 1 fromnode 5 tonode 3
movement 2 fromnode 5 tonode 6
movement 3 fromnode 5 tonode 1
movement 5 fromnode 1 tonode 3
movement 6 fromnode 1 tonode 6
movement 10 fromnode 3 tonode 6
movement 11 fromnode 3 tonode 1
ALLWAY 0
node 3
movements 9
movement 1 fromnode 7 tonode 4
movement 2 fromnode 7 tonode 8
movement 3 fromnode 7 tonode 2
movement 5 fromnode 2 tonode 4
movement 6 fromnode 2 tonode 8
movement 7 fromnode 8 tonode 2
movement 9 fromnode 8 tonode 4
movement 10 fromnode 4 tonode 8
movement 11 fromnode 4 tonode 2
YIELD 2
1 2 6 9
7 2 3 11

```

road section has a critical density of 30 vpm and a jam density of 240 vpm and the factor is 2.0 as the example, the critical occupancy of the targeted link will then be calculated by,

$$k_o = \frac{30}{240} * 2.0 = 0.25$$

Following the global critical density multiplier, each ramp meter is then defined in details. In this example, Node 46 is a ramp metering node which uses ALINEA strategy; while Node 52 is a pre-timed ramp metering node. It is necessary to specify ramp link, upstream link and downstream link for all ramp metering nodes. In addition, bottleneck link, update cycle, parameterKR and detector location are only required by ALINEA type meters, while one can simply input 0 after the comment text for pre-timed meters. For node 46, the ramp link is from node 119 to node 46; Adjacent upstream and downstream links for the ramp are from 137 to 46 and from 46 to 223, respectively. ALINEA algorithm requires the bottleneck link to be specified. The bottleneck link is the link with a targeted flow rate. In the example, it is the link from 46 to 223, the same as the adjacent downstream link. ALINEA also requires knowing the duration

Table 3.2: Sample Signal File Format: Ramp Metering
Ramp Metering Counts: 2

2.0

Merge Point: 46
Algorithm: ALINEA
Ramp Link: from 119 to 46
Upstream Link: from 137 to 46
Downstream Link: from 46 to 223
Bottleneck Link: from 46 to 223
Update cycle: 120
Parameter K_R (v/h): 70
Detector Location: 0.1
Initial Rate: 424

Merge Point: 52
Algorithm: PRETIME
Ramp Link: from 152 to 52
Upstream Link: from 63 to 52
Downstream Link: from 52 to 67
Bottleneck Link: from 52 to 67
Update cycle: 120
Parameter K_R (v/h): 70
Detector Location: 0.1
Initial Rate: 450

of time to update the metering rates; this is specified as “Update cycle: 120” in the example, that is, for every 120 seconds the algorithm will update the metering rate for the next cycle. The default value of ALINEA modulating parameter K_R is 70 v/h; and this parameter can be specified by users. Detector location is specified in the unit of miles, and it is measured as the distance from the head node of the bottleneck link. “Initial rate: 450” specifies the metering rate for the ramp when the analysis period starts. Pre-timed ramp metering control shares the same data structure with ALINEA algorithm, with the only exception of initial rate for PRETIME is the de facto metering rate for the overall analysis period.

In order to consider multiple metering rates by time of day in the analysis period, multiple control plan (with *.mtp* extension) must be prepared to input to NetZone.

3.5 Multiple plan control

Multiple control plan file (with *.mtp* extension) specifies the time-of-day control for both intersection nodes and ramp metering nodes. A sample *.mtp* file is shown in Table 3.3. In the current version of NetZone, multiple timing plans can only be used for pre-timed controlled nodes. In the example, one pre-timed signalized intersection and one pre-timed ramp meter are defined. Note that no comment text should be input in the *.mtp* file. The multiple plan control file must be prepared by users manually and cannot be generated by the GUI at this moment.

Table 3.3: Sample Control file: Multiple Control Plan (*.mtp*)

```

2

2
2 900 2700
1 4
1 1 3 1 2 3
1 2 3 1 2 8
1 3 3 10 11 12
1 4 3 4 5 6
11 11 11 11
21

2 4
2 1 3 1 2 3
2 2 3 1 2 8
2 3 3 10 11 12
2 4 3 4 5 6
10 20 20 5
10

26
4 900 1200 1200 300
1 660
2 450
3 720
4 900

```

The first line of the *.mtp* file specifies the number of controlled nodes that are deployed with multiple control plans. It is then followed by the details of multiple plans for each node.

For the signalized intersection nodes, one does not need to specify the movement information again for the multiple plans. In the block of a specific node, the first line specifies the node ID number. The next line specifies the number of plans and the duration of each plan. For

example, Node 2 has two pre-timed control plans. The first plan is performed from the starting time of the analysis horizon to 900 seconds, while the second plan starts from the end of the first plan and lasts 2700 seconds. The sum of the durations must be consistent with the analysis horizon.

The successive information bulks are for each of the control plan for node 2. For example, the first plan is given ID 1 and has four phases. The next four lines are phase definitions similar to the single pre-timed nodes. Then the next line is the duration for each phase and the successive line defines the offset for the plan. Note that the whole bulk of information is similar to that of a definition of a pre-timed signal node except for the cycle is not explicitly defined. Rather, here the cycle is calculated as the sum of phase durations. The next bulk defines a plan labeled with ID 2 for Node 2.

Following the block of specifying control schemes for Node 2, the next block defines multiple plans in detail for the ramp metered Node 26. Node 26 has four metering rates effective during the analysis horizon, each of which has a duration of 900, 1200, 1200 and 300 seconds, respectively. The next four lines give the ID numbers for each of the plan and the effective metering rates accordingly.

3.6 Local Synchronization Control (LSC)

Local synchronization control (LSC) generally refers to the level of timing coordination, or synchronization, between adjacent signalized intersections and metered ramps. Three types of LSC are modeled in the current version of **NetZone**,

- An on-ramp meter and an adjacent signalized intersection that feeds the traffic into the on-ramp.
- An off-ramp and an adjacent signalized intersection that receives traffic from the off-ramp.
- Two adjacent signalized intersections. This type of LSC is used for the case where the connector link between the two intersections is particularly short.

The LSC is optional to the dynamic network simulation, that is, the local synchronization control file (with *.lsc* extension) does not have to be present in the network folder to run the simulation. However, LSC can greatly reduce the queue spillback in certain cases. Since it has been widely deployed in the real world, it is highly suggested to provide the *.lsc* file for those critical intersections or ramps with severe congestion. The local synchronization control file must be prepared by users manually and cannot be generated by the GUI at this moment.

An LSC unit improves the system performance by detecting the severe queue and eliminating its spillback to upstream links and thus potential gridlock. An LSC unit is then composed of detection, determination of potential queuing spillback and synchronization of control actions. Note that the signalized intersection node within an LSC unit must be designated to the type of vehicle actuated. Table 3.4 illustrates an example of LSC for two signalized intersections and a pair of intersection and ramp.

The first line of the *.lsc* file gives the total number of LSC units. Then each LSC unit is defined in details. Each LSC unit is given a unique unit ID in the first line of the block defining an LSC unit, followed by the unit type indicator. The unit type indicator, 1 and 2, indicates the synchronization of a pair of ramp metering and adjacent intersection and the synchronization of adjacent signalized intersections, respectively. Therefore, LSC unit 3 synchronize the signals between two intersections, while LSC unit 7 sets a strategy to coordinate the signals in the upstream intersection and the downstream ramp. For type 2 LSC, additional node-link pairs can be added to enhance the efficiency of the LSC. The node-link pairs are other internal meters deployed with LSC strategies in addition to the primary LSC units (signals). The node in the node-link pair is also a node with vehicle actuated control and the link feeds traffic to the congested link(s) (targeted link and detection links) in the primary unit. A more detailed description of each line in the *.lsc* file can be found in Table 3.4.

3.7 Signal control in GUI

Although users can provide NetZone with control text files to input traffic control information, it is usually not convenient nor straightforward to most users. NetZone provides user-friendly GUI to help users input control schemes without knowing formats of text files. At this moment, multiple plan control and local synchronization control are not supported by GUI.

Once a control node is selected and NetZone is under the control edit mode, users can open a dialog to input control schemes by right clicking on the selected node.

For intersection signal control, a dialog is shown in Figure 3.4(a) and (b). In the tab of “timing phases”, users can add and delete phases, modify the offset of the intersection, set the duration for each phase for pre-timed signal control, or set the minimum/maximum green time and extension interval for actuated signal control. In the tab of “phase movements”, all the possible movements in the intersection are listed for users’ information. Users can add or delete any of those movements for each phase. If the control node is under priority control, then a dialog, as shown in Figure 3.4(c), pops up. Users can choose either an all-way stop sign or a

Table 3.4: Sample Control File: Local Synchronization Control (*.lsc*)

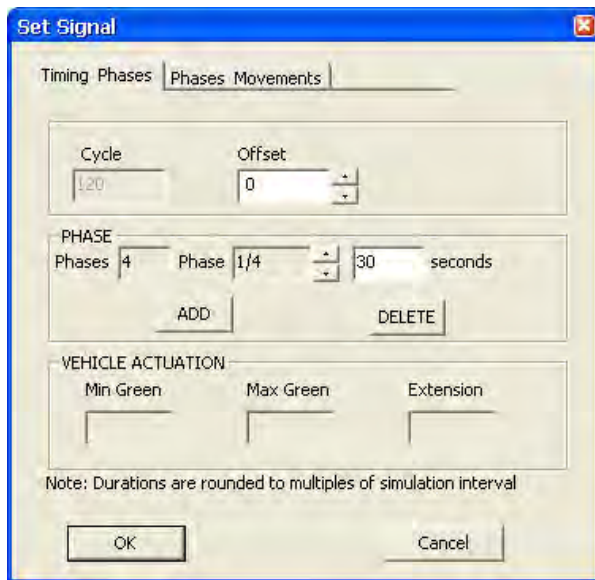
2	2: total number of LSC units
Unit 3 1	3: unit id; 1: type
Signal(node): 218	218: signal(AD) node id
ramp(node): 571	571: ramp (freeway) node id
queuing detector: 0.22	0.22: location of queue detector, measured from the downstream of the target link
intensity: 0.5	0.5: critical occupancy that triggers LSC actions
Target link: 61	61: target link id. target link is where the detector is located
Feed Link: 503	503: feed link id; for off-ramp LSC, the feed link is where the traffic comes from (last link of the off-ramp); for an on-ramp LSC, the feed link is where the traffic goes out of the signal node.
detection links: 2 1312 1314	1: number of additional detection links besides target link; 1312 1314: detection link id
Unit 7 2	7: LSC unit id; 2: type
Signal(node): 19	19: signal node id
Ramp(node): 249	249: ramp node id
queuing detector: 0.12	0.12: queue detector location, measured from the downstream of target link
intensity: 0.5	0.5: critical occupancy that triggers LSC actions
Target link: 1228	61: target link id
Feedto Link: 90	503: feed link id
detection links: 2 90 4250	1: number of additional detection links besides target link; 90 4250: detection link id
Adjustment: 1	1: multiple factor to adjust the maximum green time of AD node; extend the maximum green to the multiple of loading intervals
node-link pairs: 1 35 46	1: number of node-link pairs; 35: node id; 46: link id

yield sign. For the yield sign, users can first add the yielding movements and then specify their corresponding yielded movements.

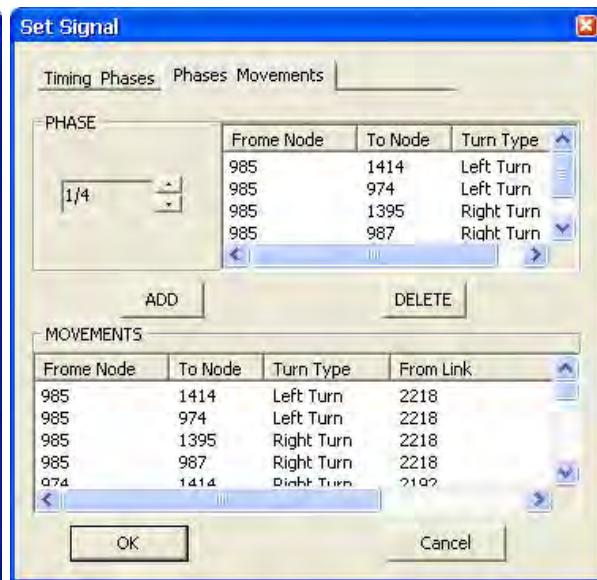
A dialog as Figure 3.4(d) is used for ramp metering nodes. Regardless of which type of ramp metering strategy is chosen, ALINEA or pre-timed, users need to input the ID number of the ramp link, upstream link, downstream link and the bottleneck link by choosing from

associated links that connect to the node. Pre-timed ramp metering requires a desired flow discharging rate (i.e., **Initial Rate** in the dialog), while users need to input all the parameters in the dialog for ALINEA.

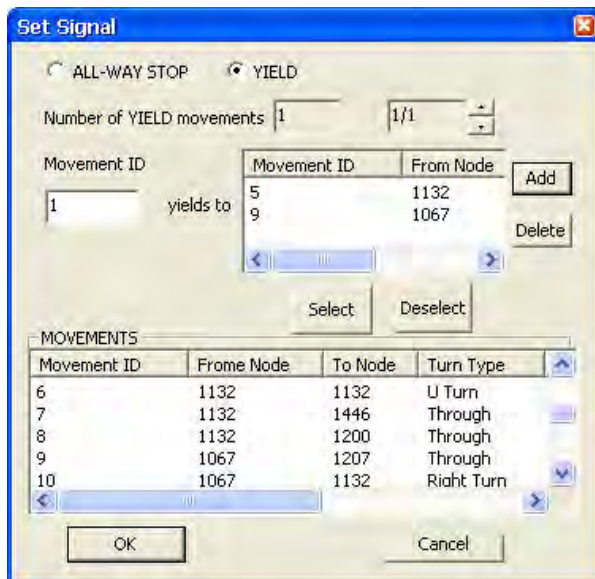
In both the intersection control and ramp metering control case, after confirming the information with the OK button, NetZone can automatically write control information to the control file which will be read by NetZone before a simulation is performed.



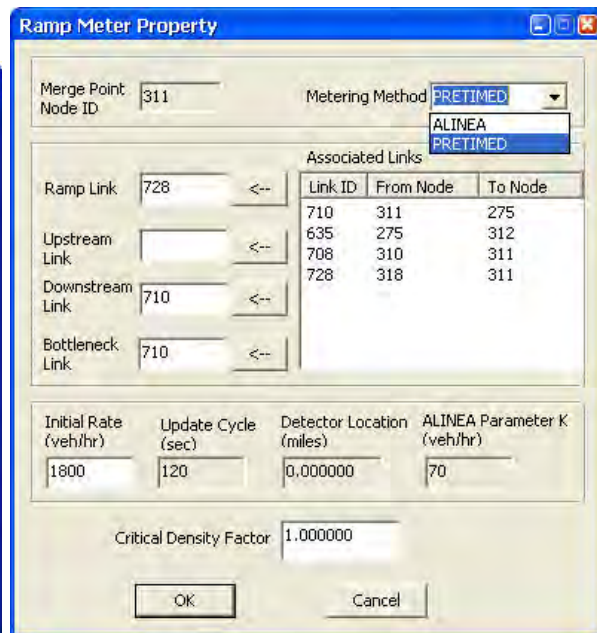
(a) Movement setting for signal control



(b) Timing setting for signal control



(c) Movement setting for priority control



(d) Parameter setting for ramp metering

Figure 3.4: The dialog of inputting control information

Chapter 4

Emission model

The emission module was added in **NetZone** to calculate the fuel consumption and the emissions of the network during the analysis time period. The emission includes carbon dioxide (CO₂), carbon monoxide (CO), hydrocarbon (HC) and nitric oxide and nitrogen dioxide (NO_x). Following mainstream microscopic emission models, we compute emissions and fuel consumptions using **aggregate average speed** and **Vehicle-Miles-Traveled (VMT)** as the major input.

The network dynamic simulation produces the travel times and travel routes of all the trips during the analysis time period. The results can be used to compute time-dependent average speed and VMT for each link. Mobile 6 (EPA 2001) is one of the most commonly used Vehicle Emission Modeling Software. We adopt the VMT-based emission models in Mobile 6.2 to estimate emissions of HC, CO and NO_x. Also, **NetZone** incorporates the most recent studies in statistics regarding the relationships between the average speed and fuel consumptions/greenhouse gas (EPA 2001, FHWA 2009). Finally, **NetZone** provides two methods to compute total network emissions and fuel consumption.

4.1 The method of directly calling MOBILE 6.2

NetZone first calculates the average speed and the hour-based VMT of each link throughout the network, for every hour of the simulation horizon. **NetZone** will then output an emission file with *.ems2* extension where the hour-based VMT distribution and the speed-based VMT distribution over the required 14 speed bins in Mobile 6 for two road types (freeway and arterial roads) are provided. This file can be used as the input to call Mobile 6 directly to calculate the emission rates (grams per mile) of HC, CO and NO_x. Finally, the total emission (tons) of HC, CO and NO_x can be computed manually. On the other hand, fuel consumption and CO₂ emissions computed by Mobile 6 may be rough approximation to the real values because

both fuel consumption and CO₂ emission rates are not sensitive to the speed-based VMT or hour-based VMT distribution. Therefore, this method is only used to compute emission of HC, CO and NOX.

4.2 The method of implementing microscopic emission models in NetZone

The transportation Energy Data Book shows a recent study on the relationship between fuel economy and average vehicle speed (FHWA 2009). The data points in that study were fit by a polynomial regression model (See Section 4.3 for the regression models and fitting curves). Then the fuel consumption rate is computed as follows,

$$\text{Fuel consumption rate (gallon/mile)} = \frac{1}{\text{fuel economy}} \quad (4.1)$$

We assumed that all carbon in the fuel contributes to CO₂ emission after flaming. Hence, the CO₂ emission rate is calculated by,

$$\text{CO}_2 \text{ emission rate (gram/mile)} = 8875 * \text{fuel consumption rate (gallon/mile)} \quad (4.2)$$

The microscopic emission models of HC, CO and NOX are based on the speed correlation factor provided by EPA (2001). As all the vehicles are standardized to be light-duty gasoline vehicles (LDGV) in the network simulation, we use “speed correlation factor and baseline predicted freeway emissions” of Tier 0 (normal emitters) in Mobile 6 to represent the relationship between average vehicle speed and emissions. The data points were also fit by polynomial regression models (see Section 4.3 for the regression models and fitting curves for emissions of HC, CO and NOX).

Those regression models provide the relationships between the average speed (over a certain time period, e.g. 15 min) and fuel consumption/emission rates. To compute the total fuel consumption and emissions, we first calculate the average speed and the hour-based VMT of each link, for every hour of the simulation horizon. The fuel consumption/emission rates are then obtained by applying those regression models. Multiplying the fuel consumption/emission rates by hourly-based VMT for each link and then adding up the fuel consumption/emissions over the entire simulation horizon and over the entire network yields the total network fuel consumption/emissions. We recommend users to use this method because NetZone provides the statistics of fuel consumptions and emissions directly for each scenario and the microscopic emission models may be more accurate than the aggregate emission models used by Mobile 6.

4.3 Microscopic emission models

This section gives polynomial regression models and fitting curves for emission rates of HC, CO and NOX (gram per mile) and fuel economy (miles per gallon). Let v denote the average speed.

The fuel economy is calculated as follows and its fitting curve is shown in Figure 4.1,

$$\begin{aligned} \text{fuel economy} &= -1.47718733159777 * 10^{-13}v^{10} + 6.8247176456893 * 10^{-11}v^9 \quad (4.3) \\ &\quad -1.38867659079602 * 10^{-8}v^8 + 1.63502795565324 * 10^{-6}v^7 \\ &\quad -0.000123021415999858v^6 + 0.00616148672549657v^5 \\ &\quad -0.207343000174098v^4 + 4.61456181374348v^3 \\ &\quad -64.856033832593v^2 + 519.768517199759v - 1780.82307640254 \end{aligned}$$

where $15\text{mph} \leq v \leq 75\text{mph}$. Whenever the average speed is less than 15 miles/hour (or higher than 75 miles/hour), the fuel economy at 15 miles/hour (or 75 miles/hour) is used, respectively.

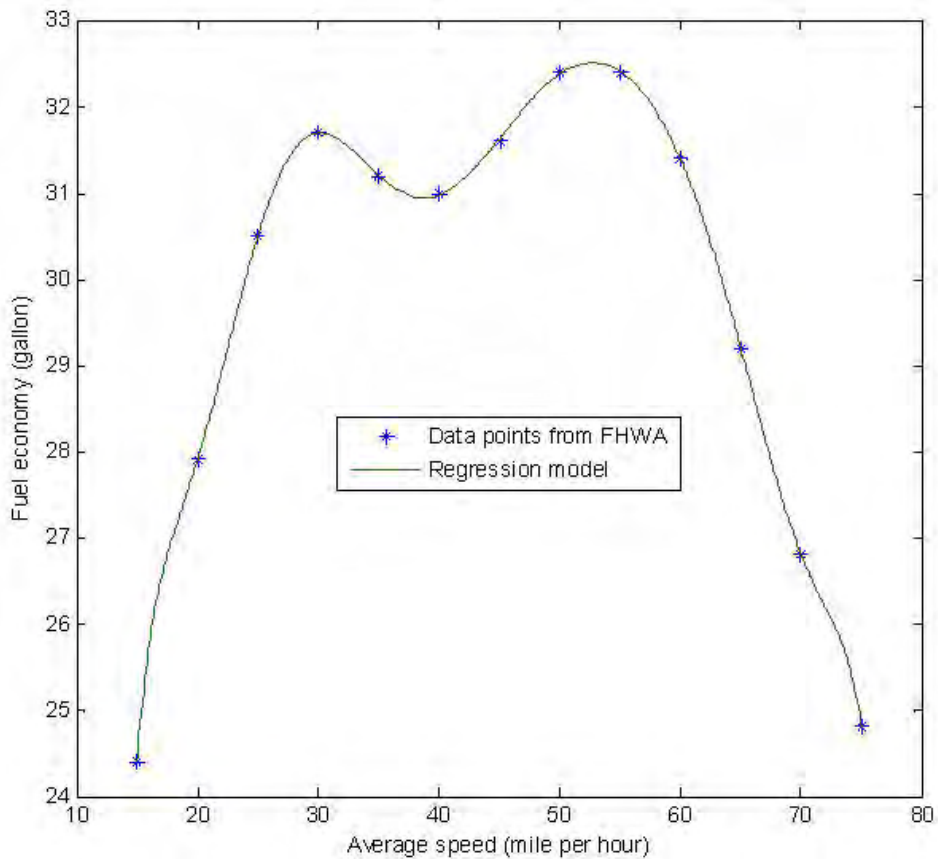


Figure 4.1: Fitting curves and data points of fuel economy with respect to the average speed

The emission rate of HC is calculated as follows and its fitting curve is shown in Figure 4.2,

$$\begin{aligned}
 \text{HC Emission Rate} &= 1.61479076909784 * 10^{-13}v^8 - 1.27884474982285 * 10^{-10}v^7 \quad (4.4) \\
 &+ 2.92924270300974 * 10^{-8}v^6 - 3.23670086149171 * 10^{-6}v^5 \\
 &+ 0.000201135990745703v^4 - 0.00737871178398462v^3 \\
 &+ 0.15792241257931v^2 - 1.82687242201925v + 9.84559996919605
 \end{aligned}$$

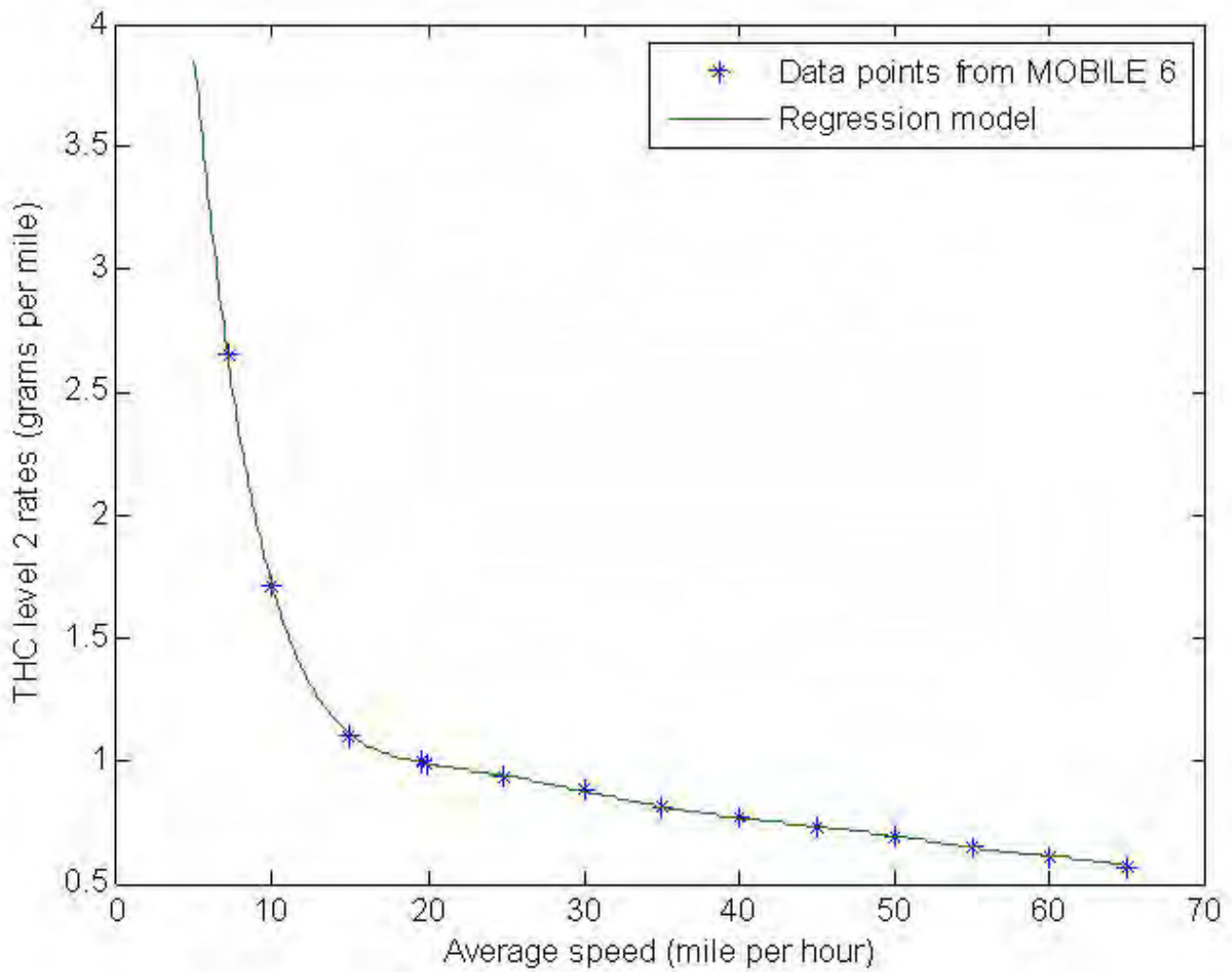


Figure 4.2: Fitting curves and data points of hydrocarbon with respect to the average speed

The emission rate of CO is calculated as follows and its fitting curve is shown in Figure 4.3,

$$\begin{aligned}
 \text{CO Emission Rate} &= -1.08317411174986 * 10^{-12}v^8 + 2.53340626614398 * 10^{-10}v^7 \quad (4.5) \\
 &- 2.12944112670644 * 10^{-8}v^6 + 5.97070024385679 * 10^{-7}v^5 \\
 &+ 1.79281854904105 * 10^{-5}v^4 - 0.00170366500109581v^3 \\
 &+ 0.047711166912908v^2 - 0.615061016205463v + 4.12900319568868
 \end{aligned}$$

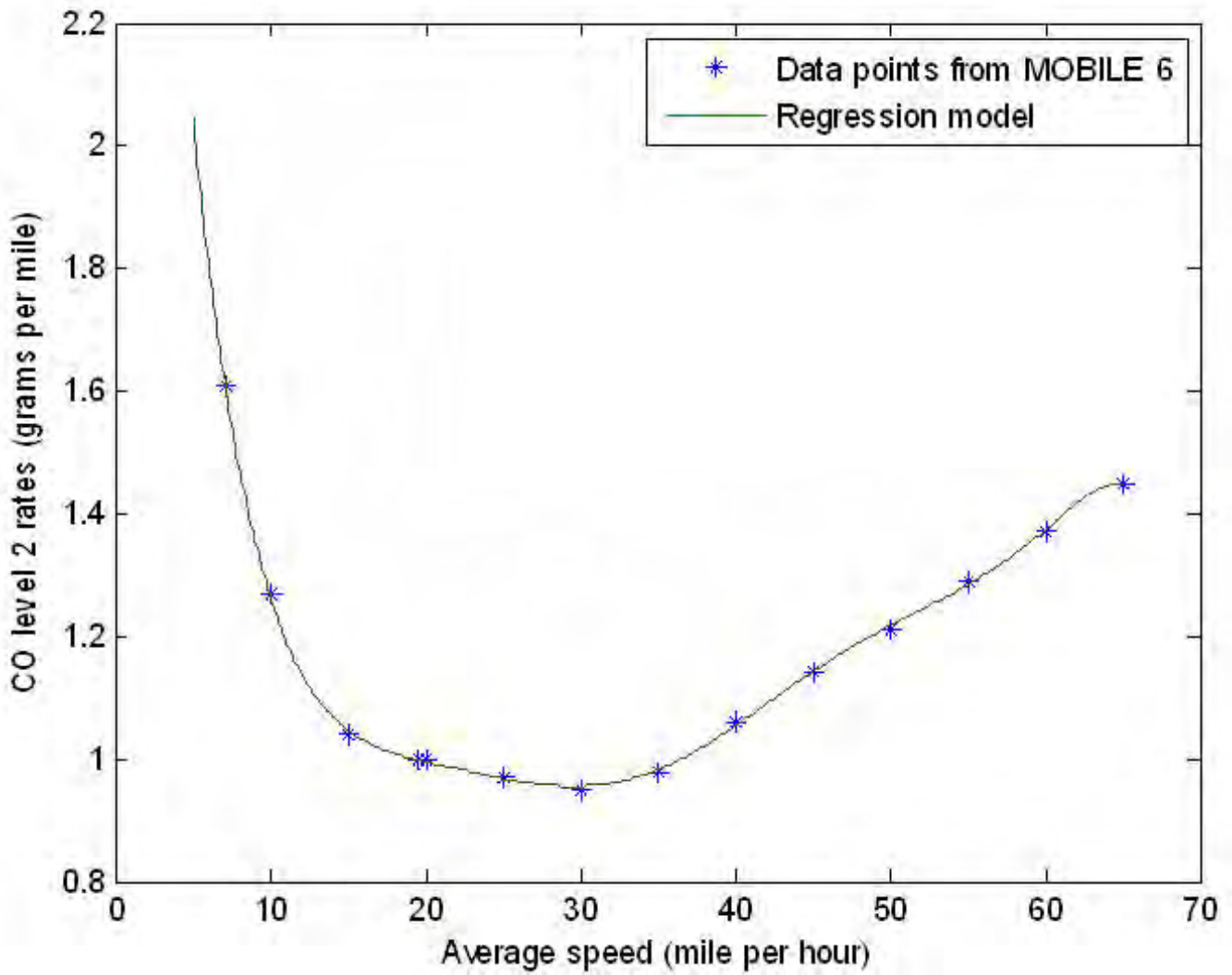


Figure 4.3: Fitting curves and data points of CO with respect to the average speed

The emission rate of NOX is calculated as follows and its fitting curve is shown in Figure 4.4,

$$\begin{aligned}
 \text{NOX Emission Rate} &= -6.52009367269462 * 10^{-13}v^8 + 1.25335312366681 * 10^{-10}v^7 \quad (4.6) \\
 &- 4.67202313364846 * 10^{-9}v^6 - 6.63892272105462 * 10^{-7}v^5 \\
 &+ 8.01942113220463 * 10^{-5}v^4 - 0.00374632777368871v^3 \\
 &+ 0.0895029037098895v^2 - 1.07265851515536v + 6.06514023873933
 \end{aligned}$$

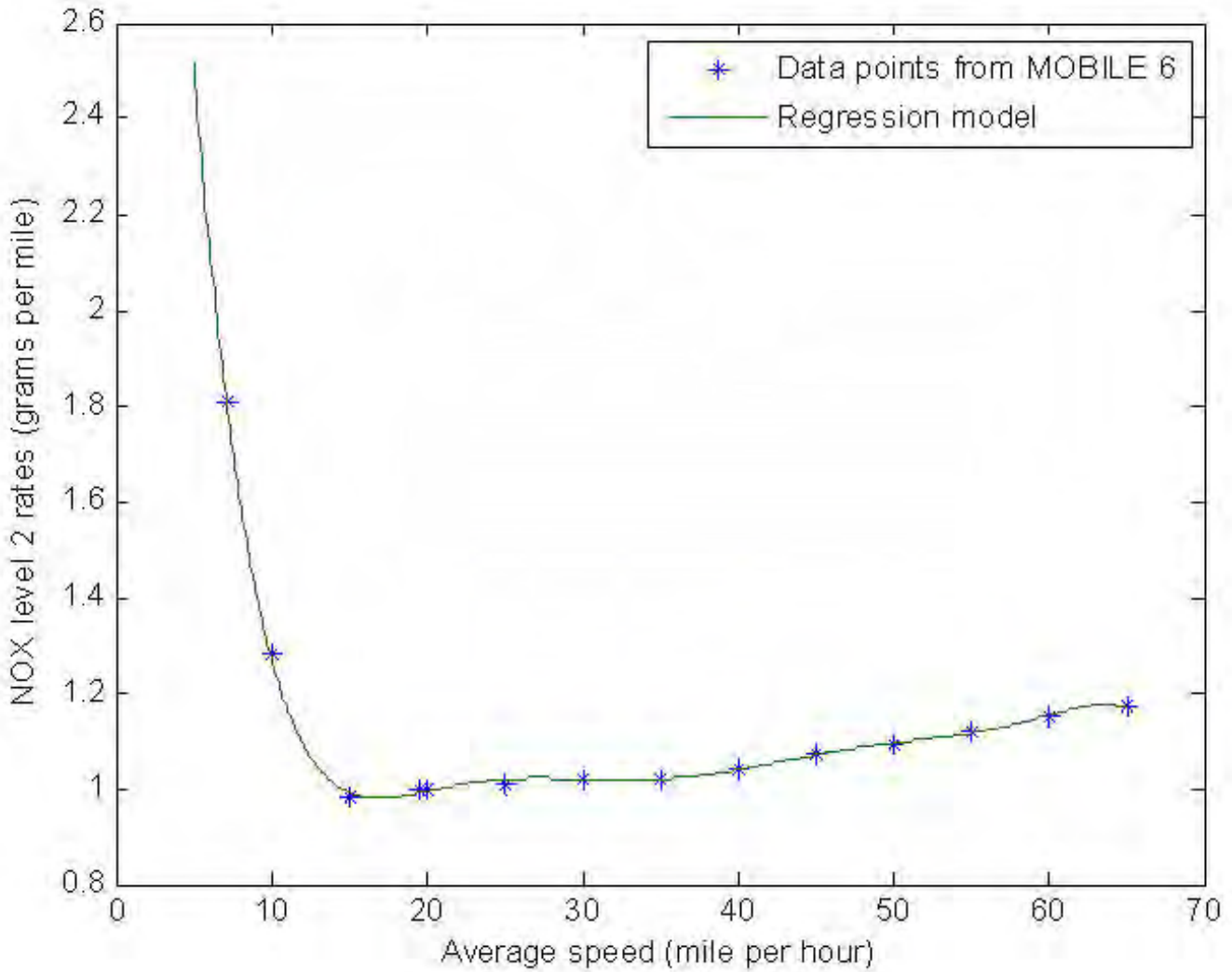


Figure 4.4: Fitting curves and data points of NOX with respect to the average speed

For the regression models regarding emissions of HC, CO and NOX, $5mph \leq v \leq 65mph$. Whenever the average speed is less than 5 miles/hour (or higher than 65 miles/hour), the emissions rate at 5 miles/hour (or 65 miles/hour) is used, respectively.

Chapter 5

Graphical User Interface Enhancement

The previous version of NetZone has Graphical User Interface (GUI) for network preparation, data visualization and performance analysis. However, the way the GUI was organized may be complex for novice users. In addition, there is a need to improve the appearance of the software and to add more functionalities to the data visualization. New dialogs and windows should also be designed for new NetZone models. This chapter describes how the new GUI in NetZone is organized, particularly for those new functionalities.

5.1 New Menu organization and appearance

The menu items of NetZone are re-organized to provide a more user-friendly graphical user interface (GUI). The new main menu features a clear work flow consisting of the following four components: Project, Network, Workzone and Evaluate. These four menu items are consistent with the four-step work flow of NetZone. The new GUI provides a variety of ways for data visualization and toolbar/status bar choices in the View menu. The toolbar icons are also upgraded with a more professional appearance. The main window of the new NetZone is shown in Figure 5.1.

The basic functions of each menu item are listed in Table 5.1 and a snapshot of the sub-menu items is shown in Figure 5.2. A detailed description of the menu commands of NetZone is presented in NetZone's user manual, and not repeated here.

5.2 File import and export

The previous NetZone constructs a network by either adding objects (such as links and nodes) in the GUI or importing network files with the specific NetZone format. However, most of the

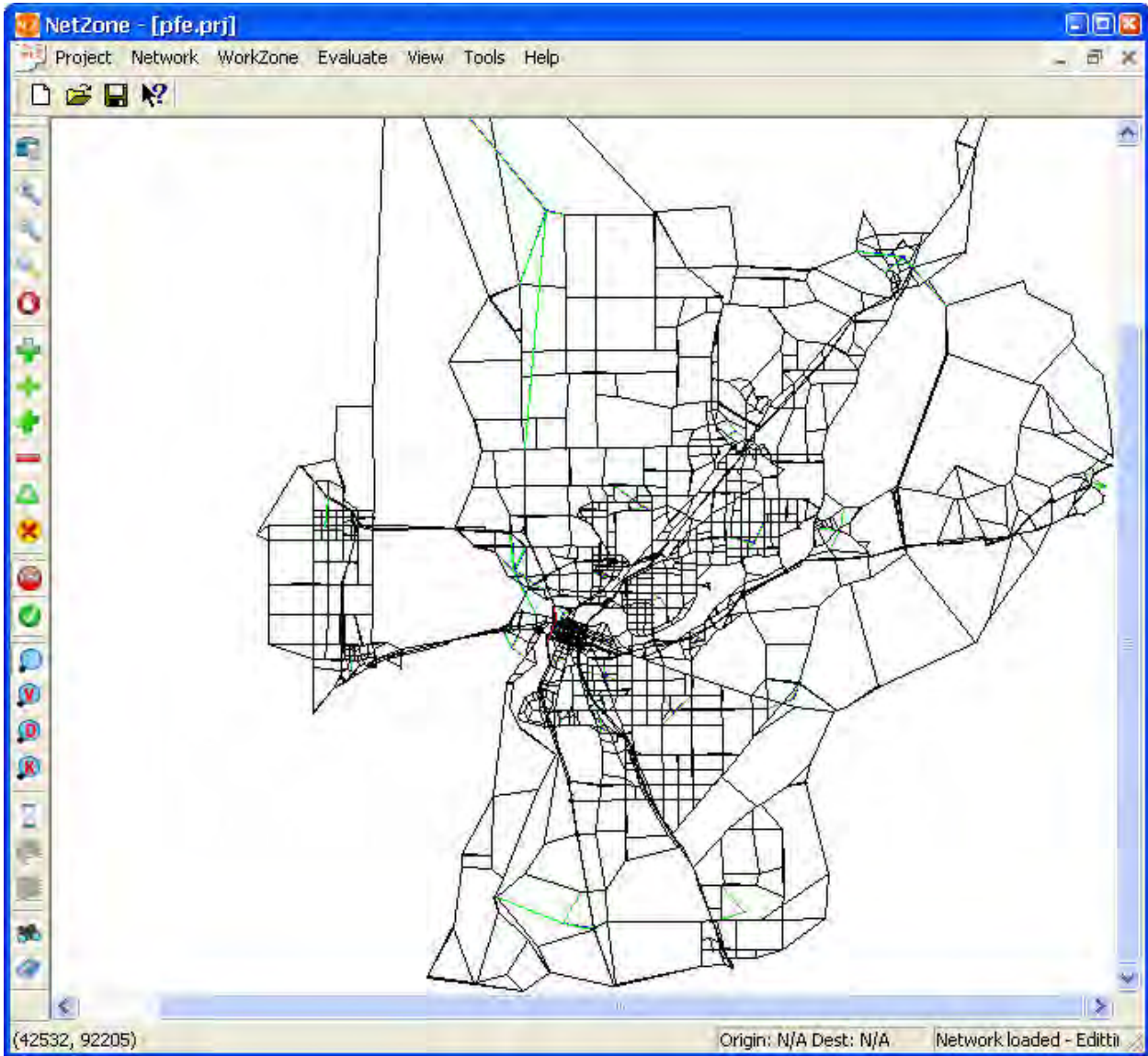


Figure 5.1: The main window of NetZone

Table 5.1: NetZone menu items and their functions

Menu item	Functions
Projects	Project settings, file import/ouport
Network	Editing of networks, signal timing and O-D demands, map visualization/diagnostics tool
WorkZone	Work zone layout and associated traffic management plan, simulation and replay
Evaluation	Comparison of the MOEs of different scenarios
View	Visualization tools for display, data files and windows, toolbar/status bar settings
Tools	Other useful tools to facilitate analysis
Help	Help information for NetZone

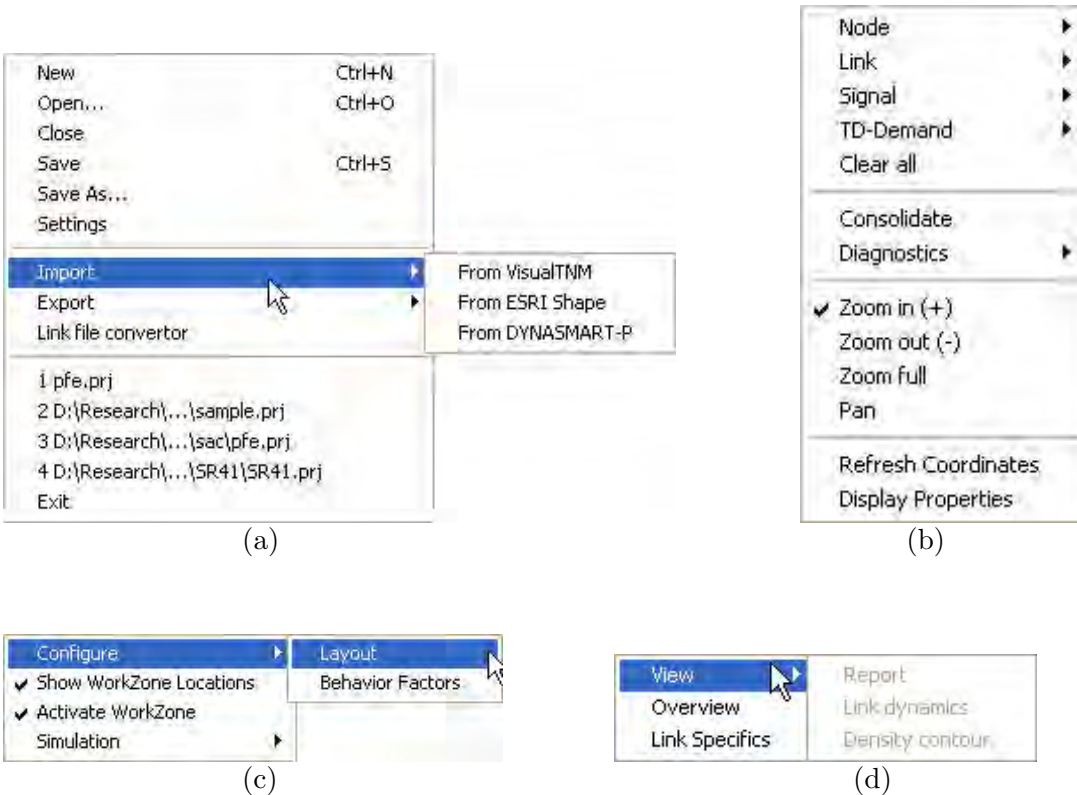


Figure 5.2: (a) The Project menu; (b) The Network menu; (c) The Workzone menu; (d) The Evaluate menu

large-scale networks are stored in the format of GIS shape files, a commonly used file format compatible with mainstream transportation software and GIS software. It would provide users much convenience to directly create networks in NetZone from those GIS networks with full or partial roadway information, and to further use/show the results from NetZone in other software. This facilitates the interaction between NetZone and other transportation/GIS software and helps users to save time in editing networks in both NetZone and other software.

The input/output work flow of NetZone has been completely re-designed. The NetZone can import and convert GIS shape files to create a network directly, as shown in Figure 5.3. On the other hand, once users finished editing the network in NetZone, they can export the NetZone network to a standard GIS shape file which contains all link attributes used in NetZone, as shown in Figure 5.4.

The import function comes with the option where users can choose to retain key fields (such as speed limit, length, capacity, etc.) of the GIS shape file in the NetZone network. Besides transferring the necessary information to NetZone, the conversion process also checks the network topology and adds to NetZone links that are not represented in the GIS shape file but necessary

for NetZone. This is because a GIS shape file usually presents the network topology in the form of one-way links. In other words, a road segment with two opposite directions is recorded as only a one-way link in the shape file, while its directional property (e.g., one-way or two-way) may be otherwise recorded only in a field of the link attribute table. In fact, such a road segment is usually represented by two directional links in a transportation network unless it allows only one-way traffic. Therefore, we also developed a tool to help users to resolve this issue. If users provide the name of the field in the attribute table which indicates whether a GIS-based link is one-way or two-way (0 denotes two-way and 1 denotes one-way), then the conversion process can add a directional link opposite to each of the GIS-based links whenever the link has an attribute of 0 in that field. If otherwise such a field name is not provided, then the conversion process will double the total number of links in the NetZone network by automatically adding a link opposite to each of the GIS-based links.

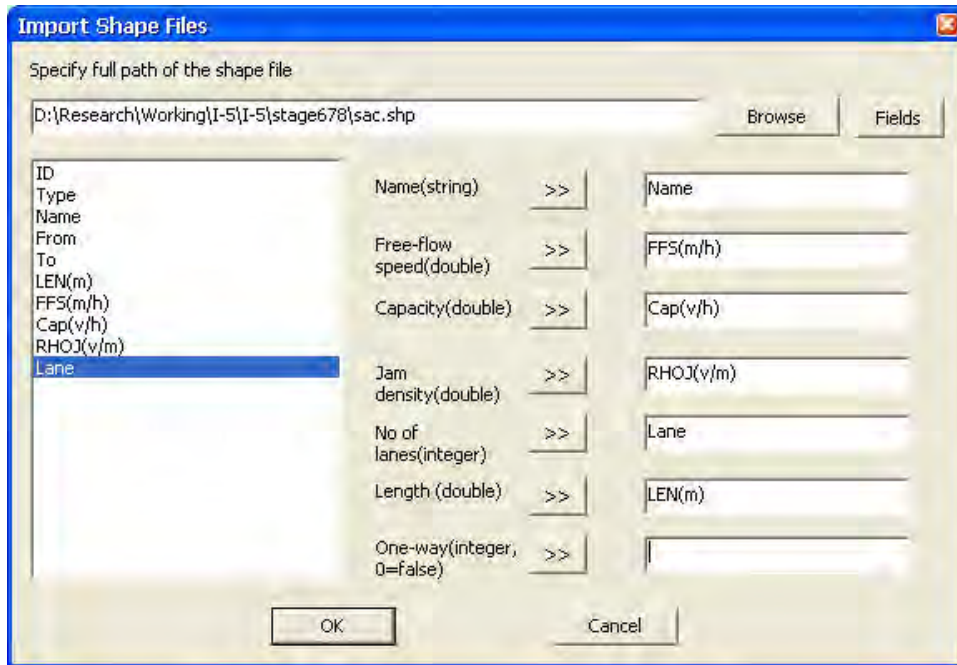


Figure 5.3: The Import Shape Files dialog

5.3 Network visualization and editing tools

We re-designed the visualization of links and nodes in NetZone. In the previous version, all the links in NetZone can only be displayed in straight lines without any intermediate vertices. This results in unrealistic display of those curved links. For example, Figure 5.5 shows how the interchange of I-80 and US-50 in Downtown Sacramento was displayed in the previous NetZone.

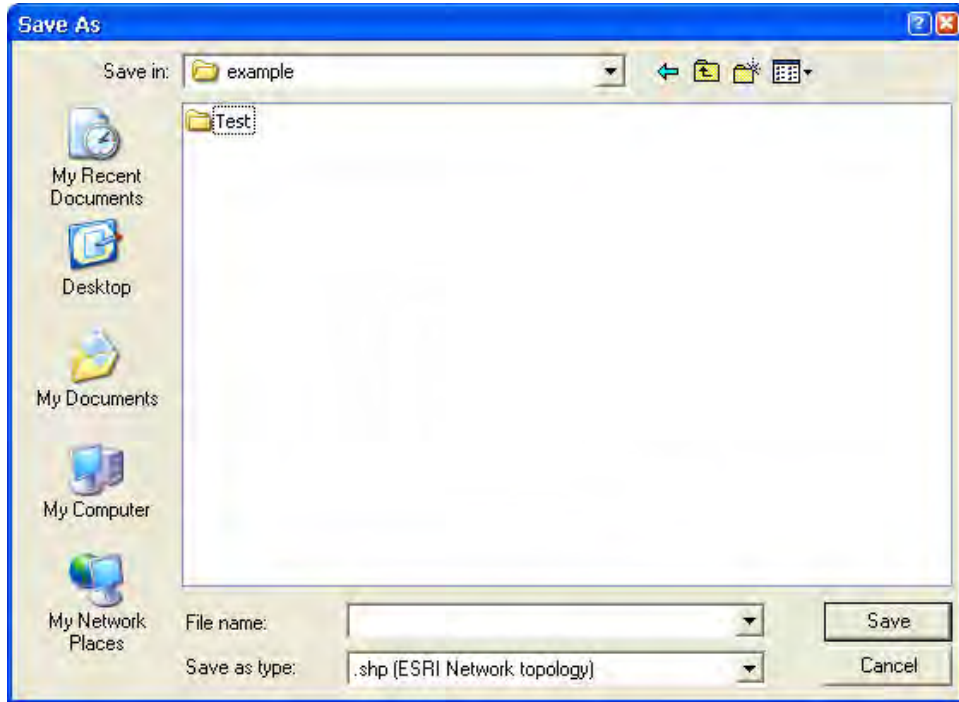


Figure 5.4: The dialog of shape file export

Because those curved ramps that connect both freeway routes can only be displayed in straight lines, the view of those ramps in NetZone could be far from the actual shapes, which may mislead or confuse users. The new NetZone provides a realistic view of all types of shapes for roadway links. The links are displayed in the format of polylines, and both the positions and the number of the vertices in the polylines are unlimited. Therefore, users can add sufficient vertices for curved lines to approach its actual shape. The interchange of I-80 and US-50 in Downtown Sacramento, for instance, can now be displayed as in Figure 5.6, which is consistent with the actual view.

A text file, with *.vet* extension, is used to store all the geometry information for those vertices. There are three ways to display links in polylines with intermediate vertices. First also the most convenient way is that NetZone can automatically retain all the vertex information from the GIS shape file when it is imported to construct a network. In this way, all the links can be displayed in the same view as shown in the GIS software. NetZone will automatically save the vertex information to the *.vet* file which is further attached to the project file. Second, if no such GIS shape file is used to create the network, then users can draw the curved links from scratch by adding vertices sequentially as shown in Figure 5.7(a). The vertices will be recorded cumulatively in the *.vet* file. Third, users can also write a *.vet* file in a specific format and

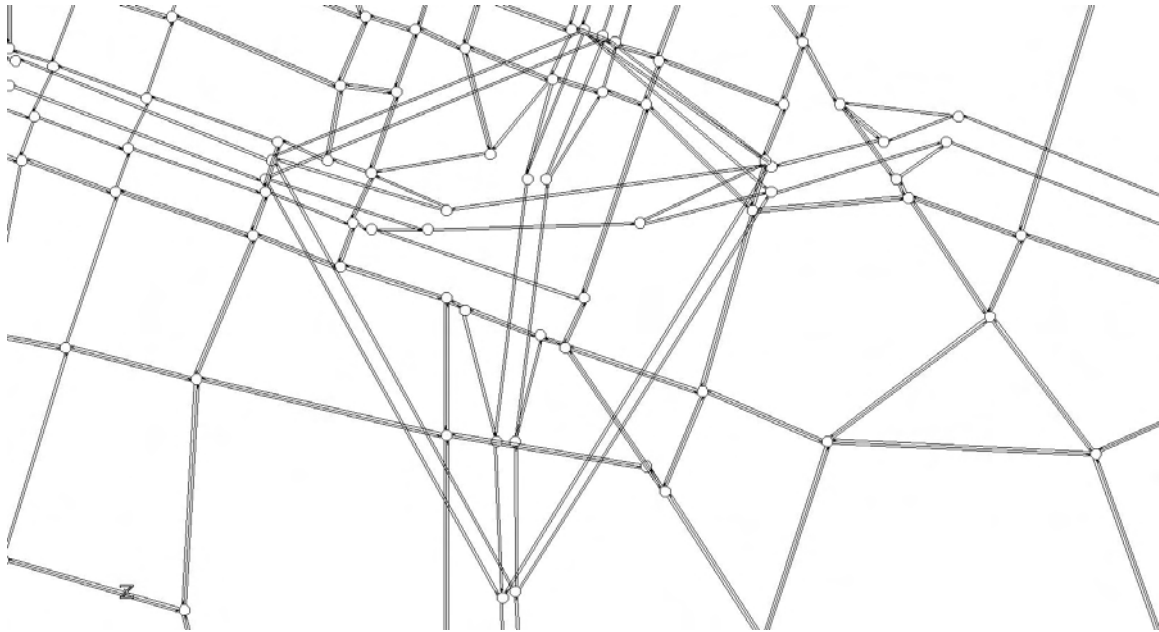


Figure 5.5: The interchange of I-80 and US-50 in Downtown Sacramento displayed in the previous NetZone



Figure 5.6: The interchange of I-80 and US-50 in Downtown Sacramento displayed in the new NetZone

provided it in the project folder. NetZone can automatically read this vertex file and display all curved links. The format of the vertex file is described in details in the User's Manual. Note that although the links are displayed in a more realistic view in the new NetZone, the underlying

link model used to analyze dynamic network performance remains the same as before. Vertices are not considered during the network simulation. Of all the geometric information, only the total lengths of links are used for the simulations purposes.

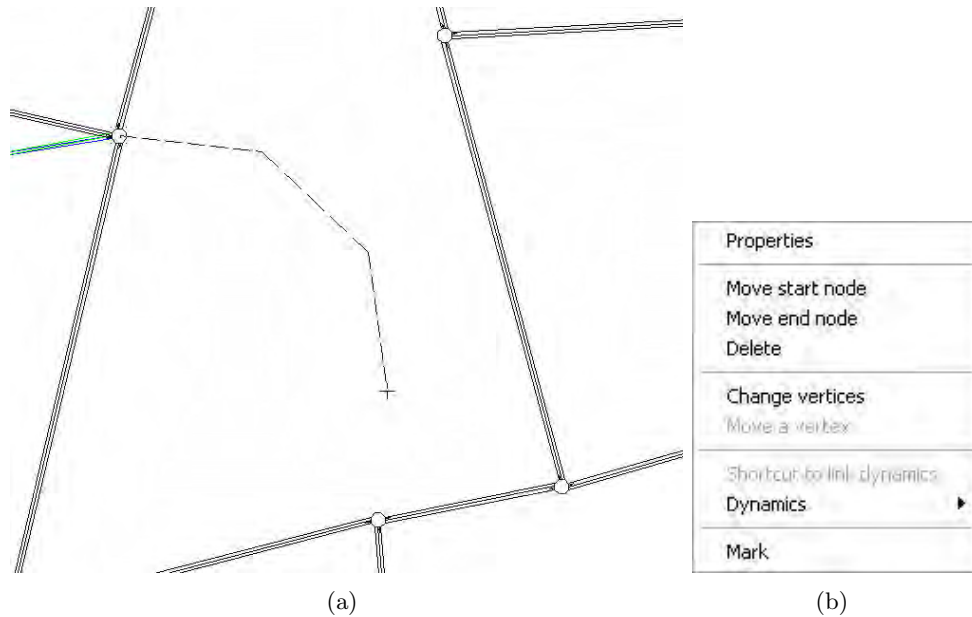


Figure 5.7: (a) Draw a curved link by adding vertices sequentially; (b) Network editing options

Since there is a fundamental change in the visualization of links and nodes, a number of functions associated with adding, editing and deleting links and nodes were added to the NetZone GUI. Meanwhile, the GUI is enhanced with more network editing options as shown in Figure 5.7(b). The view of links with cell divisions, particularly under simulation replay, is also updated accordingly to accommodate the new visualization design.

The Zoom functionality in the view of networks in NetZone has been improved. A new menu item, Pan, is now added for users to drag a network around without changing the display size, as shown in Figure 5.8.

In addition, more details on the links are modeled in the new NetZone. The link properties now contain street names and HOV attributes as shown in Figure 5.9. The street names and HOV attributes can be entered in either the link property dialog or data files, and can be viewed and edited by users.

5.4 Network diagnose

A series of diagnostic tools are implemented to help users check network errors and diagnose possible inconsistency when the networks are externally imported. In fact, many networks

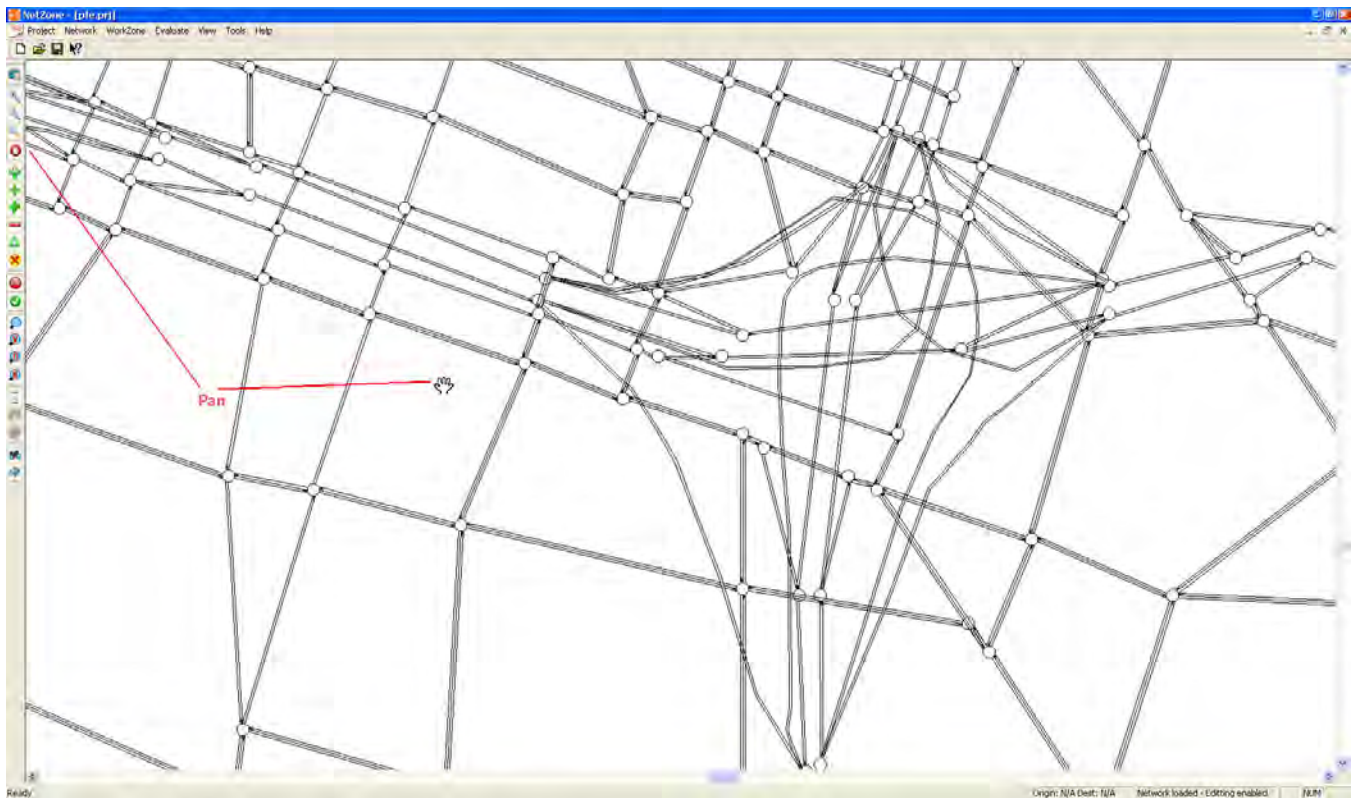


Figure 5.8: A new menu item, Pan, can be used to drag a network around

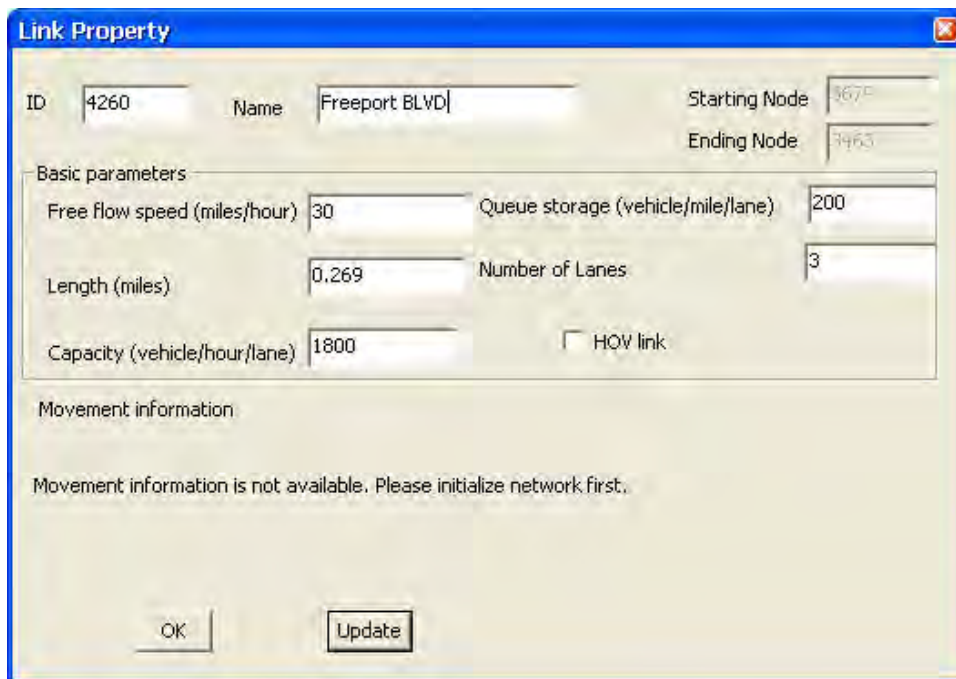


Figure 5.9: The Link property dialog

used in work zone traffic impact assessment are imported from other sources such as traffic simulation software packages (e.g., Paramics, Dynasmart, etc.) and transportation planning software packages (e.g., TransCAD, VISUM, etc.). These networks, when converted to the NetZone network format using built-in functions, are not immediately ready to be used for network simulation. Sometimes a network contains too refined topological information which is unnecessary in work zone traffic impact analysis, while others may have problems related to connectivity and network attributes. Those issues may add unnecessary computational burdens to the simulation, and in the worst case, could result in errors in network simulation. Therefore, the following diagnostic tools are particularly helpful in the process of network encoding.

- Network encoding diagnose. The menu items are shown in Figure 5.10.
 1. Network connectivity check. The main purpose of this tool is to check whether each pair of origins and destinations is connected, i.e. there exists at least one path in the network connecting each of the O-D pairs. Any O-D pair that is not connected will be detected and its origin/destination node IDs are reported in the log view.
 2. Object ID check. This tool is to ensure that each link/node in the network has a unique ID, because any links or nodes with the same ID number may cause problems in identifying objects during the network simulation. The links or nodes with identical ID numbers will be detected and the ID numbers are reported in the log view.
 3. Connector check. Sometimes when the network is imported to NetZone, it is possible that those origin connectors are marked with the link type “DMDLK” or those destination connectors are marked with the type “DMOLK”. This tool corrects the direction of connectors and ensures the types of connectors are consistent with their actual directions. The ID numbers of those corrected connectors are reported in the log view.
- Object consolidation. The consolidation dialog is shown in Figure 5.11.
 1. Remove isolated nodes. This tool aims at removing all the isolated nodes with either zero in-degrees or zero out-degrees, i.e. nodes of Type III, IV and V in Figure 5.11.
 2. Combine adjacent links. This tool allows users to combine two adjacent links with identical number of lanes and lane capacity. This is shown as Type I and II in Figure 5.11. If “combine the sequential identical links” is checked, then those adjacent links with identical attributes will be combined. If “combine the sequential similar links”

is checked, then those adjacent links with identical number of lanes and lane capacity will be combined, while the distance-weighted average free flow speed is used for the new link.

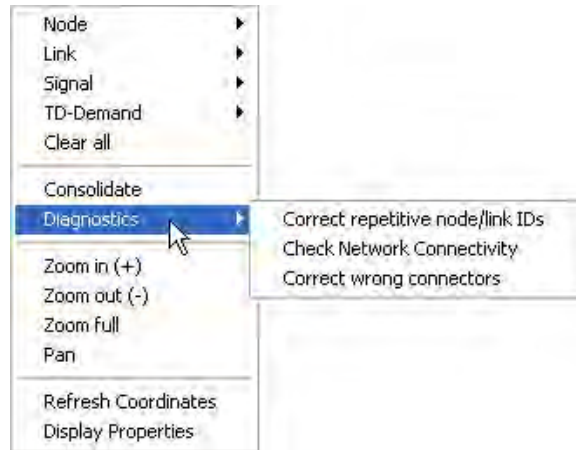


Figure 5.10: Menu items of network diagnose

In addition, the new NetZone also provides gridlock diagnostics. Whenever a network gridlock occurs during the network simulation, the ID numbers of those jammed links are listed in the log view, as shown in Figure 5.12. This can help users to analyze the cause of the gridlock.

5.5 Spreadsheet enhancement

The spreadsheet component in NetZone has been enhanced significantly. Any spreadsheet list in NetZone now are supported by the following functions,

1. Sort. By clicking the head of the column (field), the spreadsheet can sort all the records by that column (field). The increasing order and decreasing order alternate when the head is clicked repetitively.
2. Regional drag and select. In anywhere of the spreadsheet, right clicking the mouse pops up the context menu. Users can select cells in a region (rectangular), a row, a column or select all the cells. The selected cells are shown in the grey background as shown in Figure 5.13.
3. Copy and paste. Once some cells are selected, their values can be copied to another region, or to any external spreadsheet software, such as Excel.

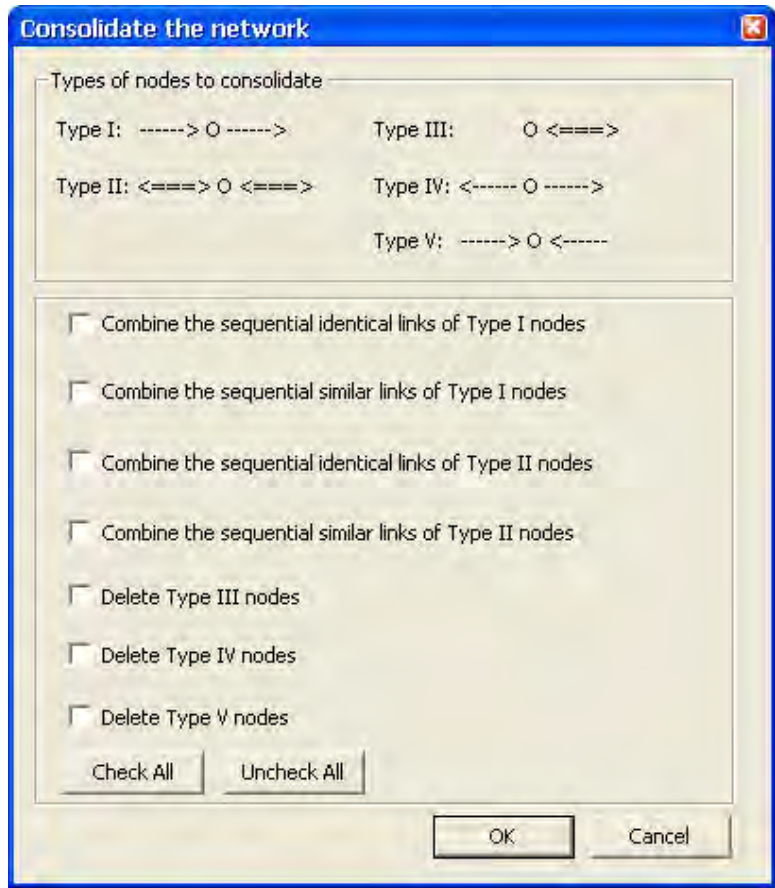


Figure 5.11: The dialog of object consolidation

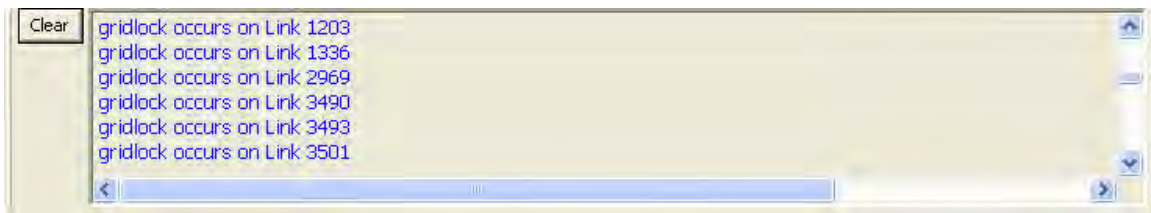


Figure 5.12: ID numbers of jammed links are listed in the log view when a gridlock occurs

4. Add/delete/edit records. Any cell can be edited, and records can be added or deleted if the number of rows in the spreadsheet is not locked up.

The screenshot shows a window titled "Statistics" containing a table with the following data:

Scenario	Tot. time (hr)	Tot. delay (hr)	Avg. time (...)	Avg. delay (...)	Max. delay (MD) (hr)	MD link ID	MD time	Max. queue (veh)	MQ Link ID	MQ time
NEW	10135.5400	5174.0181	7.5134	3.8355	0.2972	714	06:44:30	273.5000	714	06:54:50
NEW3	9634.0898	4436.7026	6.7845	3.1244	0.1167	617	06:58:50	260.5000	617	06:57:30
NEW4	12008.4034	6000.0018	8.4573	4.8046	0.3083	515	07:15:20	340.0000	515	07:19:10
NEW5	10757.4034	5379.0018	7.5755	3.9221	0.1583	1116	07:17:00	302.0000	587	07:10:20

A context menu is open over the 'NEW3' row, showing the following options:

- Synchronize
- Edit
- Select (expanded to show sub-options):
 - a region
 - a row
 - a column
 - all
- Copy

Figure 5.13: An example of the new spreadsheet menus and functionalities

Chapter 6

System improvement

We have showed that the new NetZone has significant improvement in both underlying models and GUI. This, in fact, changes the work flow in NetZone. This chapter represents, from the system point of view, the revised work flow in NetZone where users follow certain steps to perform a quick yet detailed analysis of work zone traffic impact. In addition, the improvement in computational efficiency is also discussed here. We also fixed numerous programming bugs in NetZone. Those bugs are trivial and thus are omitted in this report.

6.1 A revised work flow in NetZone

Figure 6.1 illustrates the work flow of using NetZone to perform a work zone traffic analysis task. In NetZone, each study is organized as a *Project*. A NetZone *project* combines all the data and analysis results, including network, travel demand, work zone layout, traffic management plans, assignment pattern, simulation results and all the intermediate data. Once a project is created, NetZone will automatically create a folder named by the assigned project name the path user specified. All the data associated with the project will be placed in this folder.

Starting from a blank NetZone *project*, a shape file containing network topology and an attribute table is first imported. Users can select data in the attribute table, if necessary for network analysis, to be retained in NetZone. A GIS shape file provided by a planning model may contain properties of links and node, such as length, flow capacity, number of lanes, holding capacity, free-flow speed, etc. These data are required to perform further network analysis. If they are not provided by a GIS file, then users need to enter them in NetZone by either manual input in GUI or coding the NetZone data files. NetZone also requires users to create origin and destination nodes along with O-D connectors. In addition, users are suggested to input HOV information, traffic control settings for the network. Although HOV information and traffic

control schemes are optional, they really make difference in the resultant simulation results and the presence of both are more likely to produce more realistic results.

Before dynamic simulation is performed, it is crucial to generate accurate time-dependent travel demand. The travel demand can be generated in three ways.

1. Users input traffic count data (required), travel time data (optional) and historical O-D demand data (optional), and perform the dynamic O-D estimation. After that, **NetZone** can generate time-dependent travel demands that best match those traffic data.
2. Users encode demand files and place them in the project folder (i.e. where the *.prj* file is located).
3. Users can use the build-in GUI to generate static O-D demands first, and then synthesize the time-dependent O-D demands by enforcing the demands to follow a certain profile, such as triangular or trapezoidal profile.

After the above pre-requisites are prepared, **NetZone** is ready to perform dynamic simulation. In one project, multiple *Scenarios* can be created, each of which corresponds to a different work zone layout and traffic management setting. The scenario-specific inputs include the work zone layout and the adopted traffic management plan. The baseline scenario, i.e. Scenario 0 in Figure 6.1, is the case where no work zone is present. **NetZone** stores the simulation results for different scenarios under sub-folders named by their respective scenario names. The simulation results include indicators of network performance, link specific traffic MOEs and network emissions. Users can load these results in figures and tables designed in **NetZone** for visualization purposes, and meanwhile animate the network simulation. **NetZone** provides various ways of comparing the simulation results among those scenarios and help users select the best work zone schedule.

6.2 Performance improvement

NetZone aims at work zone impact analysis for large-scale networks. Therefore, it is essential to perform network simulation efficiently without loss of accuracy. We optimized the data structure and the implementation method in the programming level to improve the software performance. In particular, two functionalities, simulation animation and link density contour plots, have been significantly improved and now can run very efficiently.

The simulation animation, i.e. simulation reply, has been enhanced with a faster and more efficient display than the previous version. In the previous version, **NetZone** only records

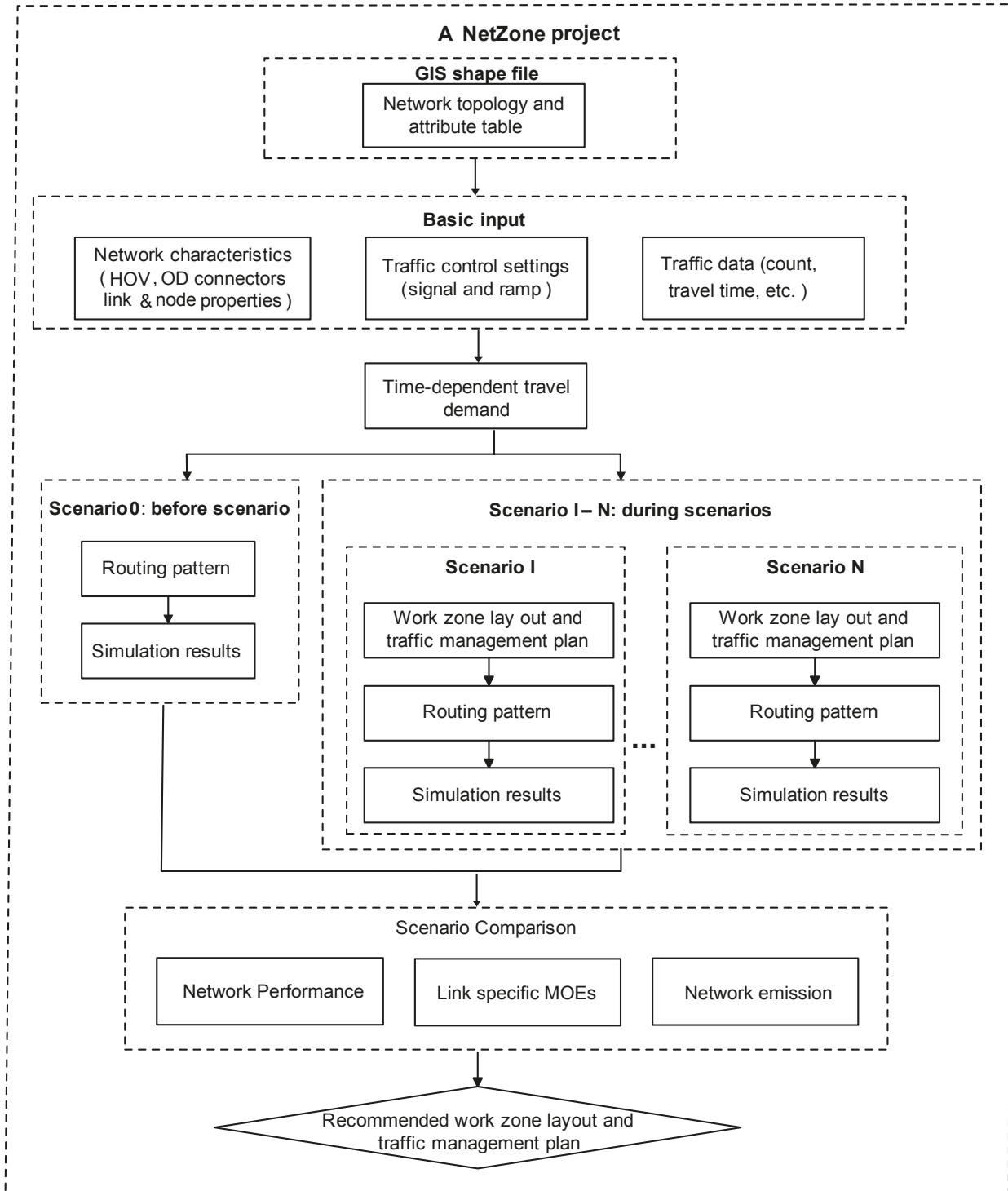


Figure 6.1: The revised work flow in NetZone

the cumulative inflow rates and outflow rates of all the links during the dynamic simulation. Under simulation animation, those rates are used to compute the density of all the cells for any particular time. This implementation can be very inefficient when users assign specific time stamp to view the animation, as the computation of cell densities is complicated and time-consuming. In the new **NetZone**, we record the density of all the cells for any particular time and write the data in a binary text file. **NetZone** can quickly retrieve density information for any cell and for any time stamp. Although the input/output of the binary text file may take extra time in the process of simulation, it is relatively negligible compared to the simulation time for a large-scale network. For a large-scale network and an analysis period with high simulation resolutions, it is possible that such binary text file takes too much space and reading it can take some time prior to the simulation animation. Therefore, we also give users an option of setting animation resolutions, as shown in Figure 6.2. A reasonably low animation resolution requires less space to store the density data and less time to process the visualization without loss of much accuracy.

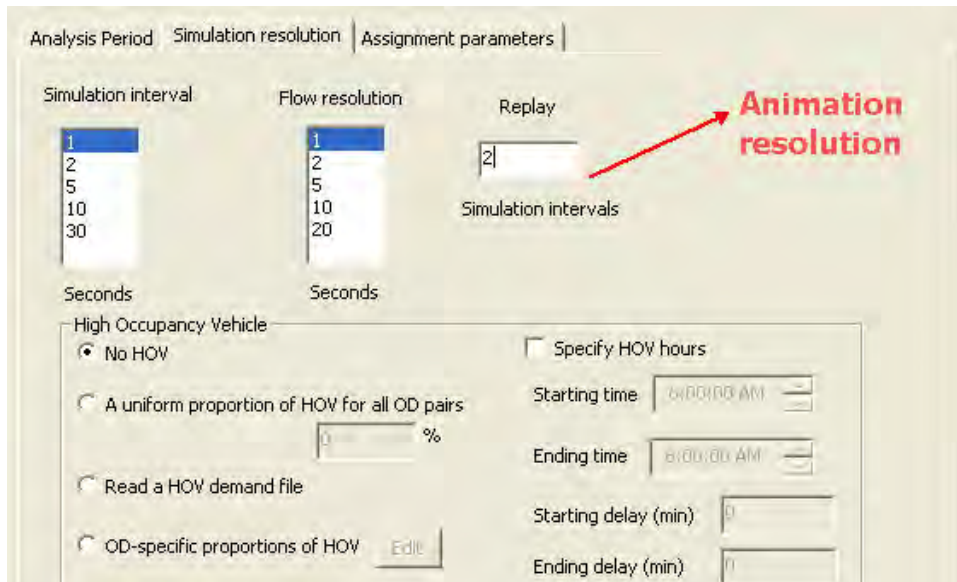


Figure 6.2: The setting of animation resolution

The same idea applies to the case of density contour plots. In the previous version, because no density information during the simulation is recorded, **NetZone** relies on the cumulative inflow rates to perform a pseudo-simulation for a single link and obtain the density for all the cells. This method clearly distorts the actual traffic propagation achieved in the network simulation and worst of all, could be very time-consuming. Since the density information for any cell and for any time stamp has been recorded in the new **NetZone**, it is efficient to retrieve the cell

density data and plot them directly in the figure. This, in fact, is both more accurate and faster for the case of large-scale networks.

Chapter 7

An overview of NetZone

We have intensively discussed the new models and functionalities implemented in NetZone and how NetZone is improved in the new version. With such change, NetZone is expected to help traffic professionals estimate traffic congestion, system performance and emissions caused by construction work zones in large-scale networks, evaluate the effectiveness of a variety of traffic management measures, and design efficient construction and traffic management plans. Unlike previous work zone traffic impact assessment tools such as the Highway Capacity Software or QuickZone which only estimate the queue on the freeway, NetZone is a dynamic network analysis tool capable of estimating network-wide traffic impact for any general networks consisting of freeway, arterials and local streets. The new NetZone is more robust and user-friendly, and it is ready for official release. This chapter provides an overview of NetZone with its key features and functionalities.

7.1 Representations of general networks

NetZone is designed for general networks of any topological types and shapes, and hence can be used for both freeway and urban networks. The fine details of each element in transportation networks are modeled in NetZone, which include, but not limited to, freeway segments (HOV and general-purpose lanes), arterial roads, minor streets, intersections, signal control, priority control, ramp metering, origins and destinations. In particular, each roadway segment has the attributes in length, speed limit, number of lanes, maximum flow rate (capacity), maximum number of holding vehicles, HOV or general-purpose lane and street name. NetZone allows users to create a general network, edit the network, or import the network from standard GIS files.

7.2 Traffic control

Signalized control, priority control and ramp metering can be modeled in **NetZone**. For intersections, **NetZone** provides pre-timed control, vehicle actuated control, stop-sign and yield-sign controls. It allows users to model pre-timed ramp metering and ALINEA metering algorithm. In addition, signal coordinations between adjacent intersections/ramps, and traffic signal schemes set by time of day help users evaluate more complicated control schemes. Those options and strategies of traffic control contribute to a more realistic simulation model in the context of dynamic networks.

7.3 Work Zone schedules

NetZone is capable of modeling complicated work zone schedules, which include lane closure, partial roadway segment closure, capacity reduction, speed limit reduction and full roadway closure. **NetZone** also considers work zone characteristics, such as weekday or weekend project and daytime or night project, as they have substantially different impact on traffic flow. The work zone plan can be set in time-of-day schedules in **NetZone**. In addition, various traffic management measures can be evaluated, which include pre-trip traveler information, media campaign, highway advisory radio and variable message signs.

7.4 Demand diversion model

In **NetZone**, a demand diversion model which estimates the reduction in travel demand and the diversion to other routes due to the construction work is developed based on data from multiple work zone projects in California. This diversion model takes into account the effects of induced delay, work zone characteristics and potential traffic management measures. For the best evaluation results, the diversion model should be further calibrated for each of the O-D pairs using the data of both the baseline scenario and work zone scenario. When data are not available to calibrate the parameters of the diversion model, **NetZone** provides users the option to specify demand reduction rates based on users' experience or judgement.

7.5 State-of-the-art simulation and assignment models

NetZone embeds a state-of-the-art polymorphic and hybrid traffic simulator. It is polymorphic in the sense that different links can be modeled by different types of traffic flow models, depending on the details one wishes to achieve. For example, if the user is only interested in how the queue

propagates along the freeway, he can set the types of freeway links as LWR links while other links as either P-Q links or S-Q links. It is hybrid in the sense that it moves *vehicular quanta* individually according to macroscopic traffic flow relations. Macroscopic models capture the essence of traffic propagation in the network, but are much easier to calibrate than their microscopic counterparts owing to their limited number of physically meaningful model parameters.

NetZone implements a hybrid-route-choice-based traffic simulation procedure. A portion of the travelers, habitual travelers, will take the pre-scribed routes according to their day-to-day experience or anticipated travel time, regardless of real-time traffic conditions on the network, while other travelers, referred as adaptive travelers, will respond to dynamic traffic conditions and choose their routes as they go. Users have the flexibility to choose the portions of habitual travelers and adaptive travelers in the network so as to produce realistic traffic conditions and network performance. Not only does the route choice model have the ability to capture travel behavior accurately, but also the simulation is computationally efficient. Our numerical examples imply that NetZone well suits real large-scale networks.

7.6 A variety of output data and statistics

NetZone provides detailed outputs and statistics at both the aggregate and disaggregate levels, which include,

- Visualization of dynamic changes in travel speed, congestion condition, queuing and density on every link segment in the entire network over simulation time periods.
- A detailed report summarizing the aggregated statistics for the network as well as for each O-D pair, such as Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT), total travel delay, average travel speed, average travel time, average travel delay, link with the longest travel delay, link with the maximum queue length, etc. All these indicators of network performance can also be viewed in the dialog of “general statistics” in NetZone to facilitate comparisons between scenarios.
- Aggregated statistics for all the HOVs, as compared to SOVs, which include Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT), total travel delay, average travel speed, average travel time and average travel delay for HOVs. These statistics are available in both the final report and the GUI.
- Aggregated statistics of fuel consumption and emission. The emission includes hydrocarbon (HC), carbon dioxide (CO₂), carbon monoxide (CO), and nitric oxide and nitrogen

dioxide (NOX) for the entire network, which are available in both the final report and the GUI. An emission file recording the time-dependent average speed of each link in the network is also output from NetZone to be used for analysis in Mobile 6.

- A variety of plots for links. The plots include cumulative flow curves, delay, volume, travel time, speed, in-out flow, and density contour. The link plots can be compared side-by-side for different scenarios.
- A standard GIS shape file exported from NetZone which carries an attribute table for both links and nodes. This is compatible with mainstream GIS and transportation software.

7.7 Flexibility

NetZone provides multiple options in nearly every step of the analysis, from input preparation to MOE generation. The flexibility allows users to choose the option they are most familiar with. It also enables users to balance the computational overhead and the solution quality, based on their specific purposes. Table 7.1 summarizes some of these options.

Table 7.1: Options available in NetZone

Step	Option
Set up the network	Constructed in NetZone GUI Imported (from Dynasmart-P or from ESRI .shp) Constructed using data files in the NetZone format
Prepare the time-dependent demand	Synthesized from static demand Estimated using traffic data (e.g. link counts, etc.) Constructed using an external demand file
Set up HOV lanes	Set up in NetZone GUI Constructed using an external HOV link file
Configure the work zone layout	Set up in NetZone GUI Constructed using an external work zone layout file
Simulation results	Visualization in NetZone GUI Summarized in report and output data files

7.8 Versatile Graphical User Interface(GUI)

NetZone implements a GUI that allows users to easily perform different types of operations, such as preparing, modifying and viewing inputs and outputs. The graphical user interface is designed to work under Windows Operation System.

The NetZone main window consists of four parts: the main menu, the toolbars, the network display/editing area and log view area. The main menu and toolbar integrate most of the analysis functions, and the network display/editing area shows the network topology and traffic simulation results. The log area outputs messages to help users diagnose possible input errors, to prompt warnings in the process of running simulation or to confirm the success of certain operations.

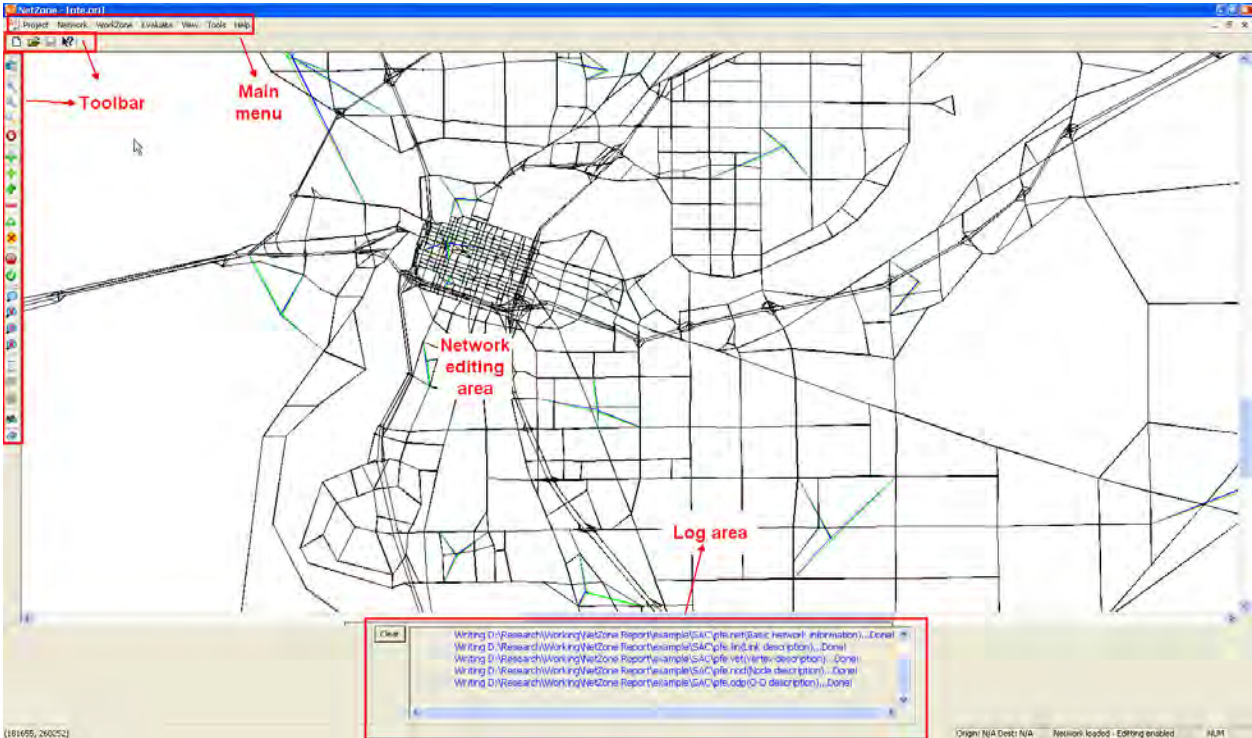


Figure 7.1: The NetZone main window

7.9 A general framework for future extension

Fig. 7.2 illustrates the basic implementation structure of NetZone. As shown, NetZone are built based on two major C++ library files (tnm.dll and mat.dll) developed over several years by Professor Michael Zhang’s research group. tnm.dll defines hierarchical network objects including nodes, links, vehicles, ODs, work zones, etc., and implements basic network operations such as shortest path searching, network construction, etc.; and mat.dll implements various types of algorithms for solving network problems, such as dynamic traffic assignment, dynamic O-D estimation etc. A graphical user interface (GUI) for NetZone is developed based on these two C++ library files utilizing Microsoft Foundation Classes(MFC), to provide users with a user-

friendly environment for performing all the work zone traffic impact assessment. Since NetZone is based on a general framework for analyzing dynamic transportation networks, it can be easily extended to evaluate a variety of traffic operational schemes besides the work zone.

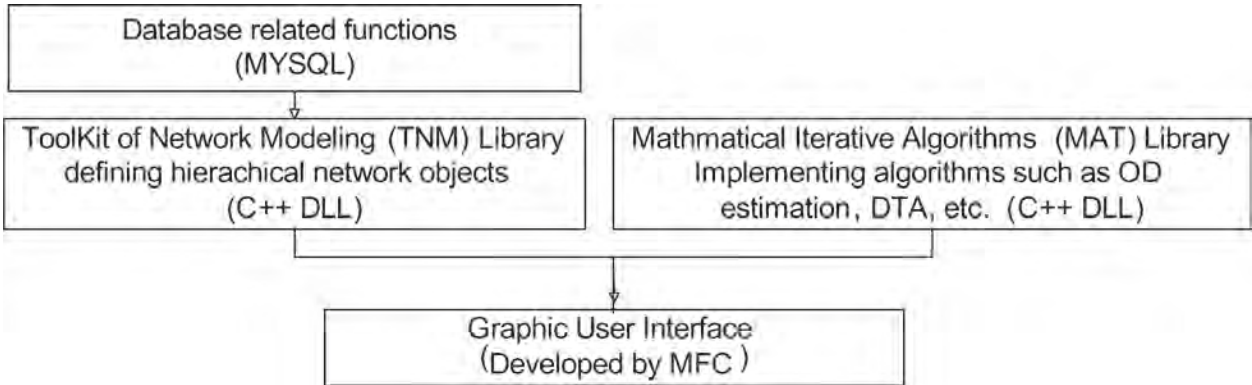


Figure 7.2: The implementation structure of NetZone

Chapter 8

Case study: Fix I-5 project in Sacramento Metropolitan Area

This chapter presents a case study, in which NetZone is used to assess the traffic impact of an actual work zone plan in a real large-scale network, i.e., the network of Sacramento Metropolitan Area with Fix I-5 workzone schedules. The case study demonstrates that NetZone is capable of dealing with realistic sizable problems, and it is also computationally efficient.

8.1 Overview of Fix I-5 project

The Downtown Sacramento portion of I-5 was completed in the 1960's and is nicknamed the "Boat Section" because it was constructed below the water level of the Sacramento River, which runs adjacent to the freeway. Caltrans engineers' estimate projected that the rehabilitation of drainage and pavement of Interstate 5 in downtown Sacramento, dubbed "Fix I-5", would take 305 working days at a cost of more than \$44 million. On February 2, 2008, the Rancho Cordova-based engineering firm, C.C. Myers, Inc., won the Fix I-5 project bid with a proposed 85 working days and 29 night and weekend schedule at a substantially lower cost of \$36.5 million, with financial incentives for earlier completion. The project was completed in a shorter period than predicted, from May 30, 2008 to July 28, 2008 in 35 days and 3 weekends using full unidirectional closures.

The Fix I-5 construction schedule periodically closed entire northbound (NB) or southbound (SB) portions of Interstate 5 through Sacramento, a relatively new technique for non-emergency construction. The boat section is on a major commuting route in an area that carries approximately 200,000 vehicles on Interstate 5 in Sacramento each day. During closure periods, traffic was detoured to arterial streets and other freeways. In order to alleviate congestion, media outreach alerted commuters about projected traffic conditions as well as advised alternative

modes of travel. Employers, including California state government which is one of the largest employers in the area with 75,000 commuters, encouraged employees to use alternative modes of travel.

The actual Fix I-5 work zone plan has six stages, i.e. Stage 2-7 as shown in Table 8.1. Stage 1 and 8 are the time periods prior to and posterior to the Fix I-5 project, respectively, where all lanes are open to the public. For each stage, we choose a Wednesday to represent a regular weekday and collected 5-min traffic data on those Wednesdays composed of two parts, vehicle counts of individual roadway detectors on major arterial roads and those of freeway vehicle counts. Because each Wednesday represents a particular week, we numbered each of those weeks as shown in Table 8.1, which will be referred in the analysis later on.

Table 8.1: Fix I-5 work zone plan

Stage No.	Duration	Closure	Representative Wednesday	Week No.
Stage 1	May 23-May 30	All lanes open (baseline)	May 28	Week 1
Stage 2	May 31-June 08	Northbound closure	June 04	Week 2
Stage 3	June 09-June 13	All lanes open	June 11	Week 3
Stage 4	June 14-June 23	Southbound closure	June 18	Week 4
Stage 5	June 24-July 08	All lane open	N/A	N/A
Stage 6	July 09-July 18	Southbound closure	July 09	Week 5
Stage 7	July 19-July 27	Northbound closure	July 23	Week 6
Stage 8	After July 28	All lane open	Aug 27	Week 7

8.2 Network description

The Sacramento Metropolitan Area original network was obtained from the Sacramento Area Council of Government (SACOG) in the format of Dynasmart. The file contains 1197 traffic analysis zones (TAZ), 14399 links and 7497 nodes. The boundaries of the network were defined as follows: the north boundary defined by Rio Linda, the west boundary defined by Davis and Woodland, the east boundary defined by Rancho Cordova, and the south boundary defined by Galt. The Dynasmart file was imported to NetZone, and the entire network is shown in Figure 8.1.

The following steps were carried out to pre-process the network before the network analysis was conducted.

1. First, we consolidate the trivial TAZs to 27 large TAZs. Each TAZ was constructed using census block information for specific cities in the SACOG region, such as the City of Davis, the City of Woodland, and the City of Elk Grove. This consolidation of TAZs provided a

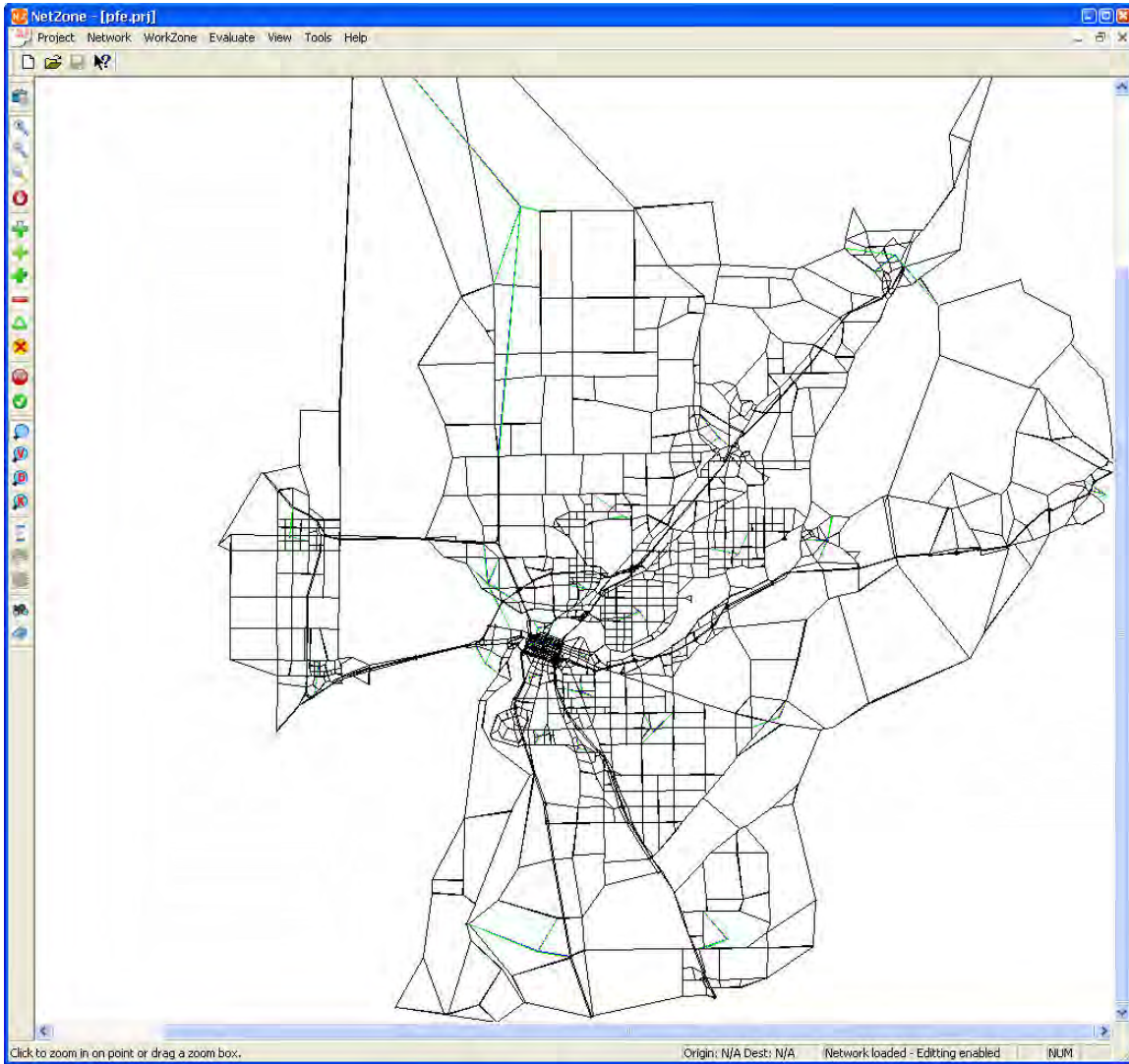


Figure 8.1: The Sacramento Metropolitan Network in NetZone

- more accurate estimation of the Origin-Destination (O-D) demands at the network level.
2. The original network was trimmed such that no “isolated” nodes and links exist. “Isolated” nodes are those who have only one forward link and one backward link, and the head node of the forward link is exactly the tail node of the backward link. Further, “isolated” links are the forward links and backward links of “isolated” nodes. The absence of such nodes and links does not affect the dynamic network analysis, but allows for a more precise estimation of network performance indicators.
 3. An origin dummy node and a destination dummy node were attached to each centroid. Therefore, the entire network contained 27 origin/destination nodes with 729 O-D pairs.

For each traffic zone, a selection set of connector nodes from the original networks within the zone was constructed. A connector node is a real network node that is neither on the freeway (or equivalently, the speed limits of both its forward links and backward links are more than 55 miles per hour) nor on the freeway ramp. Connector nodes were constructed in a different way from the regular method, because trips are most likely to start and end on local streets. In addition, we made three or four connections between real network nodes (in the selection set) and those dummy nodes, rather than those centroids directly. This method ensures through traffic will never unrealistically use connectors to reduce travel time. In addition, for those TAZs on the edge of the network (such as City of Davis), corresponding dummy nodes are additionally connected to the freeway, so that through traffic was able to be released directly on to the freeway.

4. Consolidated neighboring links with small lengths and the same speed limit. This process substantially reduced the network scale. More importantly, this was desirable to achieve more accuracy for the macroscopic traffic flow models.
5. The speed limits of all the arterial roads in Downtown Sacramento were set to 25mph~35mph.
6. The work zone plan, Northbound closure and Southbound closure, is encoded using NetZone GUI.

Even though the normal four-hour morning peak is between 6:00am-10:00am, the morning peak sometimes extends to nearly noon. Therefore, a time period of 6:00am-12:00pm (a six-hour duration) was adopted in this study as our analysis time horizon.

8.3 Dynamic Origin-Destination Estimation (DODE)

Reliable dynamic origin/destination data are critical to the dynamic network analysis. However, “true” O-D data cannot be obtained directly in most cases. Therefore, we estimate time-dependent O-D demands from link flows (traffic counts collected by vehicle detectors) using a Dynamic Origin-Destination Estimator (DODE), a build-in function provided by NetZone. The objective of the DODE problem is to obtain a time-dependent O-D table (expressed in the form of time-dependent path flows) that, once loaded onto the network, will reproduce observed link traffic counts and other observations as closely as possible.

In this project, the complete set of 28 arterial road detectors and 28 freeway detectors were available (under healthy conditions) for the selected seven Wednesdays (as discussed above).

We extracted 15-min traffic count data from selected Wednesdays for those 56 detectors which were used as input to NetZone. NetZone estimates time-dependent O-D demands in 15 minute interval based on traffic count data for each scenario. We verified the accuracy of the estimated O-D demands by comparing the estimated link flow (based on estimated O-D demands) to the observed link flow (input). The results of the verification show that the estimated link flow produced by the estimated time-dependent O-D demands for all seven scenarios (e.g., as shown in Figure 8.2 for the baseline week) effectively approximated the observed link flow. The resultant O-D demands were then used for network simulation.

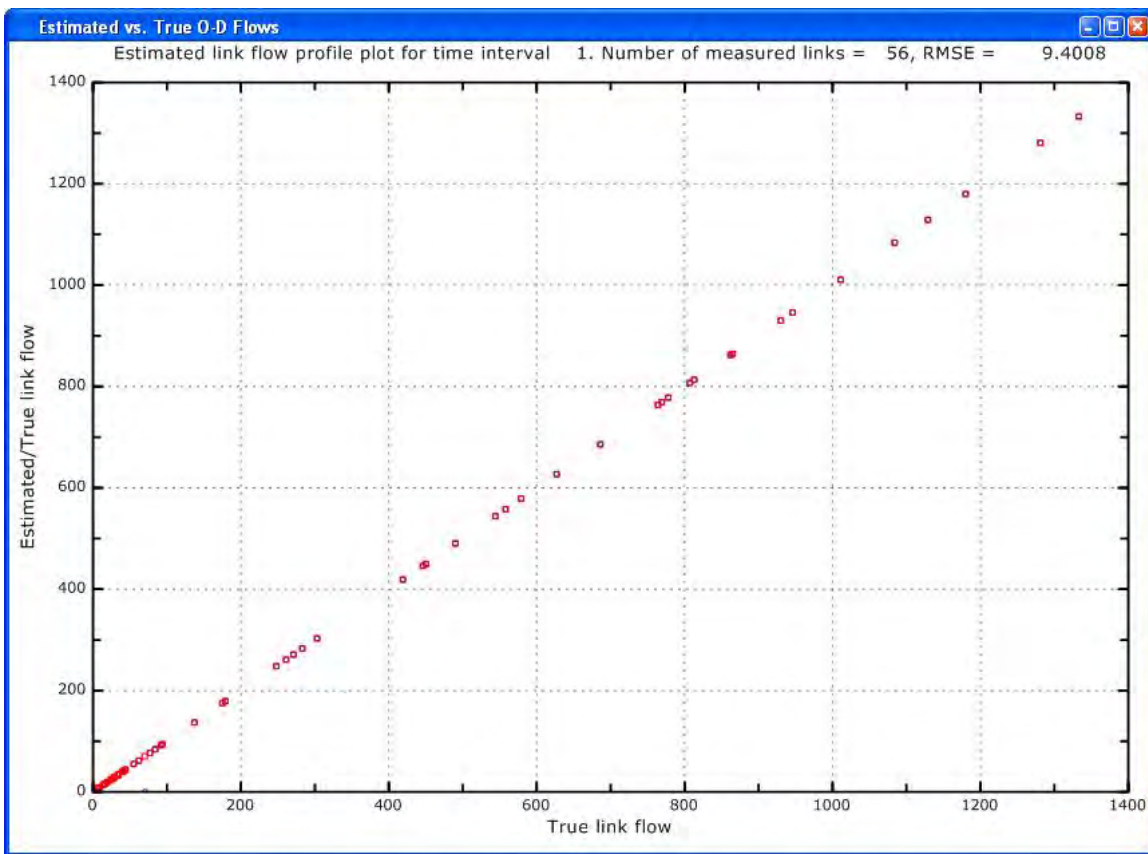


Figure 8.2: In DODE, estimated O-D demands reproduce the same link flows as the observation

8.4 Model calibration and network simulation

We performed the macroscopic network simulation for all seven scenarios. It is possible that the simulation terminates unsuccessfully because sometimes the network loading produces “grid-lock”, a condition defined as the inability of vehicles to move. This is a common issue in macroscopic network simulation. By trial-and-error, we calibrated the parameters of link prop-

erties and routing criteria such that the simulations succeeded without gridlock and meanwhile produce the traffic conditions as close as to the observed data.

We take the baseline scenario (Week 1) for an example. The network parameters are first set: loading time interval 6 seconds; $K = 3$ in the K shortest path calculation; and the traffic information will be updated every 5 minutes. Table 8.2 shows the average travel time, average travel delay and average travel distance using different diversion ratios.

Diversion ratio	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
Average travel time (min)	G	46.46	43.12	41.71	39.16	37.20	36.57	37.98	G
Average travel delay (min)	G	20.79	17.33	15.68	12.92	10.74	10.03	11.42	G
Average travel distance (mile)	G	26.29	25.79	25.63	25.47	25.26	25.24	24.31	G

Table 8.2: The total travel time and total delay of the Sacramento Metropolitan Network with respect to the diversion ratio for the baseline week (G: Gridlock)

The diversion ratio, if set too high or too low, may cause serious queuing. In this case, the simulation terminates without gridlock only when the diversion ratio is within a certain range, i.e., from 0.35 \sim 0.65. Overall, a 0.60 diversion ratio looks reasonable in the sense that the queuing pattern on freeways and major arterials is consistent with the real traffic condition. The travel times between several critical O-D pairs also match the real travel time measured by floating vehicles. For instance, the travel time from the City of Elk Grove to Downtown Sacramento is estimated to be 26 minutes and 23 minutes for northbound and southbound closures, respectively. The travel time from the City of Davis to Downtown Sacramento is estimated to be 36 minutes and 38 minutes for northbound and southbound closures, respectively. In addition, the resultant average travel time (36.57 min) and average travel delay (10.03 min) approximately match the actual perception. When the diversion ratio is smaller than 0.6, less travelers are willing to switch routes and travelers are subject to more queuing delay on average. In contrast, when the diversion ratio is larger than 0.6, more travelers respond to real-time information and switch routes, but this may cause excessive queuing on certain routes or links due to herding, which even produces a gridlock. The same trial-and-error methods are also applied to other “during-construction” scenarios. Finally, a diversion ratio of 0.85 and 0.80 is used for Northbound closures and Southbound closures, respectively.

For any network simulation that is successfully terminated, **NetZone** produces a simulation profile to provide users general information regarding network traffic conditions. The simulation profile for the baseline scenario is shown in Figure 8.3, where blue, green and red lines represent the changes in the number of en-route vehicles, moving vehicles and queued vehicles, respectively,

during the simulation horizon. The queue in the network started approximately at 6:30am, and gradually increased. The total number of trips loaded on the network achieved its peak between the periods of 7:30 AM to 8:45 AM, which is approximately the central peak hours. The worst network congestion is during the period of 7:30 AM to 9:30 AM, as indicated by the peak duration of the number of queued vehicles. The network congestion is slightly alleviated after the central peak hours. Since the input of O-D demands ends at 12:00 PM and it takes some time for those vehicles to move to their destinations, and thus there is a 90 minutes duration tail of the simulation profile (i.e., 90 minutes to clear up the network loading). The entire simulation terminates at around 1:25 PM.

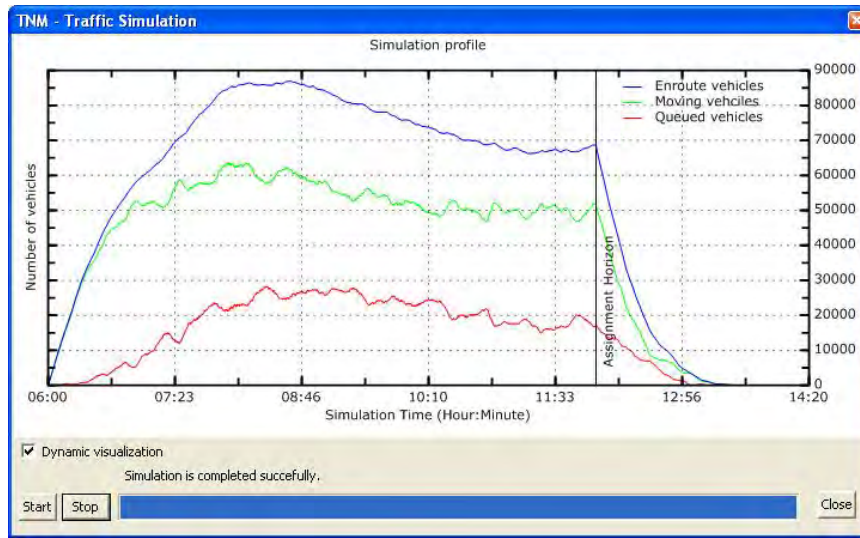


Figure 8.3: The simulation profile for the baseline scenario (open week)

8.5 Simulation results on the network performance

The simulation results on the network performance for all seven weeks are shown in Table 8.3.

Generally, the total demand traveling between 6:00 AM-12:00 PM in the network decreased for the duration of Fix I-5 project. Compared to the baseline week, weeks 3 and 7, characterized by open lanes, saw a 4,600 reduction and a 10,300 reduction in total trips, respectively. The reduction could partially be caused by the increasing gas prices, since gas prices peaked during July and August 2008. The second northbound closure had 4,000 less trips than the first northbound closure, while the second southbound closure had 10,000 less trips than the first southbound closure. This indicates that travelers tended to reduce their auto trips during the morning peak hour over the course of the construction period. The reduction may be induced

Week	Closure	Total trips (veh)	Total queuing delay (veh*hr)	Average travel distance (mile)	Average travel time (min)	Average travel delay (min)	Average travel speed (mph)	VMT (veh*mile)	VHT (veh*hr)
1	Open	359,372	60,052	25.24	36.57	10.03	41.41	9,069,100	219,025
2	NB	331,016	46,316	25.40	35.49	8.40	42.95	8,409,136	195,791
3	Open	354,755	51,557	24.51	34.42	8.72	42.93	8,695,680	203,499
4	SB	340,287	50,081	25.14	35.34	8.83	42.69	8,556,488	200,436
5	SB	330,935	50,702	25.27	35.93	9.19	42.19	8,361,132	198,188
6	NB	327,462	49,357	25.19	35.57	9.04	42.49	8,247,389	194,104
7	Open	349,013	45,556	24.47	33.47	7.83	43.85	8,538,736	194,715

Table 8.3: Simulation results for seven scenarios (weeks)

partially by the Fix I-5 project in addition to increasing gas prices during the same period. Since travelers perceived that more congestion would occur during the work zone period, they may have decided to switch to transit or eliminate some of their trips. As seen in Table 8.3, the total trips in weeks with northbound closures are slightly more than those with southbound closures. The network in northbound closures was generally more congested than southbound closures, suggesting the possibility that travelers avoided unnecessary trips in response to the congestion level.

The baseline week yields the largest average travel time (36.57 minutes per trip), and the largest average travel delay (10.03 minutes per trip). Conversely, the other two open weeks have relatively small travel delay. The average travel delay and average travel time for those construction weeks were larger than the last two open weeks (except the first northbound closure week), implying that the Fix I-5 project did increase the average travel delay for all travelers. The reason that the first open week has an exceptionally large average travel delay may be a result of the intense media coverage given to the project the week before construction started. The publicity caused a large number of travelers to tentatively detour to other routes to avoid the possible congestion during the construction period as much as they can. This is also why the first northbound closure had an exceptionally small travel delay, as many travelers switched to other traffic modes (e.g. bus, light-rail) or alternate routes which they rarely used during their regular days. Travelers may not have perceived the traffic conditions to be as bad as they expected in the first week of southbound (northbound) closure, because some travelers chose to switch back to use their original routes. Therefore, although the total demand reduced, the average travel delay in the second week of the southbound (northbound) closure is larger than that of the first week of the southbound (northbound) closure.

The changes in VMT of all seven weeks are shown in Table 8.3. Generally, the VMT of the entire network for the last two open weeks decrease by 3% and 5%, respectively, compared to the baseline week, as a result of total demand decreasing. The VMT of those weeks with active work zone is surprisingly smaller than the open weeks (except that the VMT of week 4 is slightly larger than week 7, but is still substantially smaller than the other two open weeks). This was mainly caused by a significant reduction in total travel demands with, however, slightly increased travel delay.

Besides the network performance indicators, the macroscopic simulations also yield the travel time between any two zones for all seven scenarios. Sacramento Bee on Apr. 14, 2008 reported that “travel time from Elk Grove and Laguna areas toward downtown will be Quadruple times as usual during northbound closure and double during southbound closure”. Our simulations showed the travel time from the TAZ of Elk Grove to Downtown Sacramento is approximately 26 minutes and 23 minutes for northbound and southbound closures, respectively. Comparing to “travel time of I-80/US-50 from Davis/Yolo toward downtown is undetermined during northbound closure and is predicted to be 19 times as regular weeks”, our simulation showed the travel time from the TAZ of Davis to Downtown Sacramento is approximately 36 minutes and 38 minutes for northbound and southbound closures, respectively. Our results seem more reasonable and match the real travel time measured by floating vehicles.

8.6 Simulation results on the emissions

The simulation results on the emissions for all seven weeks are shown in Table 8.3.

Week	Closure	Fuel Consumption (gallon)	CO ₂ (ton)	HC (ton)	CO (ton)	NO _x (ton)
1	Open	293,937	2,609	6.48	11.56	10.17
2	NB	273,598	2,428	5.95	10.83	9.48
3	Open	281,643	2,500	6.08	11.18	9.76
4	SB	277,128	2,460	6.09	10.93	9.60
5	SB	271,194	2,407	5.96	10.67	9.38
6	NB	267,628	2,375	5.88	10.59	9.29
7	Open	277,024	2,459	5.98	10.97	9.58

Table 8.4: Simulation results on the emissions for seven scenarios (weeks)

The changes in the emissions of CO₂, HC, CO and NO_x over the selected seven weekdays generally follow a similar pattern to that of VMT. For the three open weeks, the emissions decreased due to the reduction of total travel demand. The emissions in those weeks with active work zone were less than that of the open weeks, and they were decreasing for the duration of

Fix I-5 project. The first northbound closure week yields surprisingly low emissions, possibly due to extensive media outreach and the use of alternate routes. Anecdotal evidence suggests that work zone tends to reduce unnecessary trips. Although it contributes to the congestion, it may also reduce both the VMT and the emissions effectively.

8.7 Demonstration of visualizing results in NetZone

To examine the traffic conditions on a particular link in detail, we compare the queuing patterns on selected links among those scenarios near the construction work zone. We here use the second NB closure and the second SB closure to demonstrate the visualization of results for the comparative study.

We choose a link, ID number 7068 with the length of 1.2 miles on the upstream of I-5 NB closure segment, to plot its density contour in the open week (Week 1), the SB week and the NB week in Figure 8.4, 8.5 and 8.6, respectively. Before the construction work zone, this I-5 NB segment has only minor congestion during the middle of the morning peak. During NB closure, if no traffic management measures are implemented, traffic congestion will develop as early as 6:45AM, and this queue can spill back to its downstream links and does not relieve until noon. On the other hand, the SB closure only increases the congestion a bit, particularly between 8:45AM and 9:30AM.

One can also open the dialog of “link specifics” to make other plots for this link. As shown in Figure 8.7, once three scenarios with pre-loaded simulation results are selected, users have options of plotting a figure with respect to one of the following attributes for side-by-side comparisons, cumulative curves, travel delay, volume, travel time, travel speed and in-out flow. The plots with respect to the volume, cumulative curves, travel time and delay are shown in Figure 8.7, 8.8, 8.9 and 8.10, respectively. As expected, the NB closure results in substantial congestion and thus much longer travel time and delay on this link than the cases without work zone or with the SB closure.

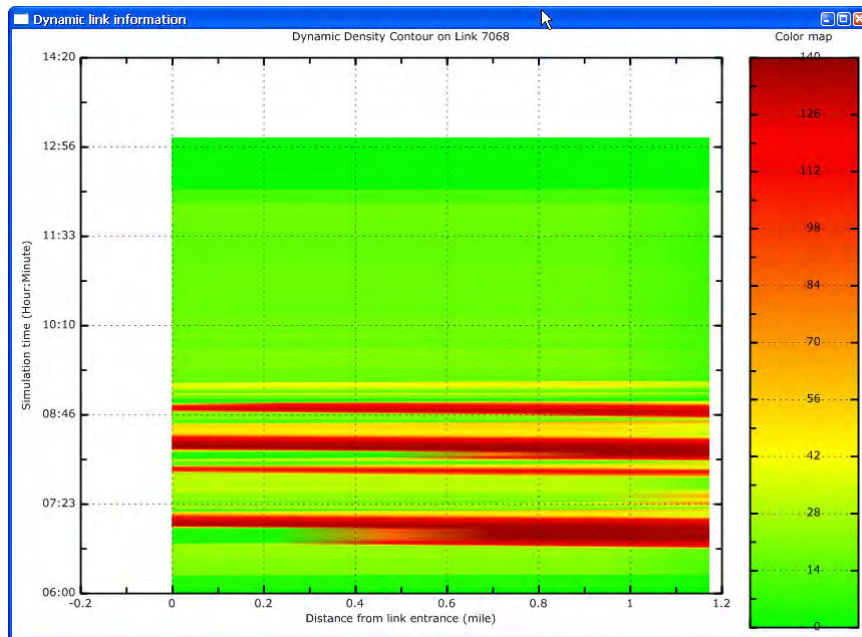


Figure 8.4: The density contour plot on Link 7068 for the open week

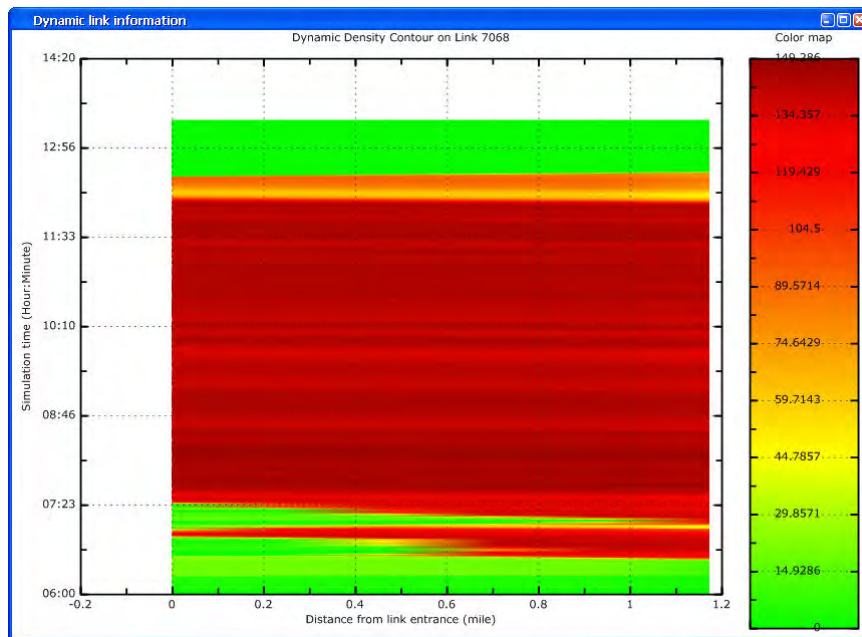


Figure 8.5: The density contour plot on Link 7068 for NB closure

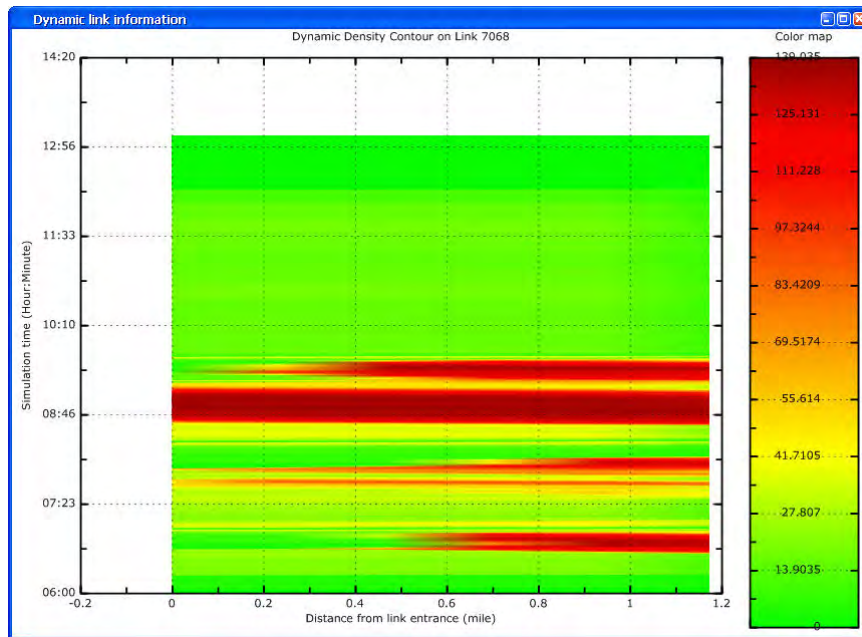


Figure 8.6: The density contour plot on Link 7068 for SB closure

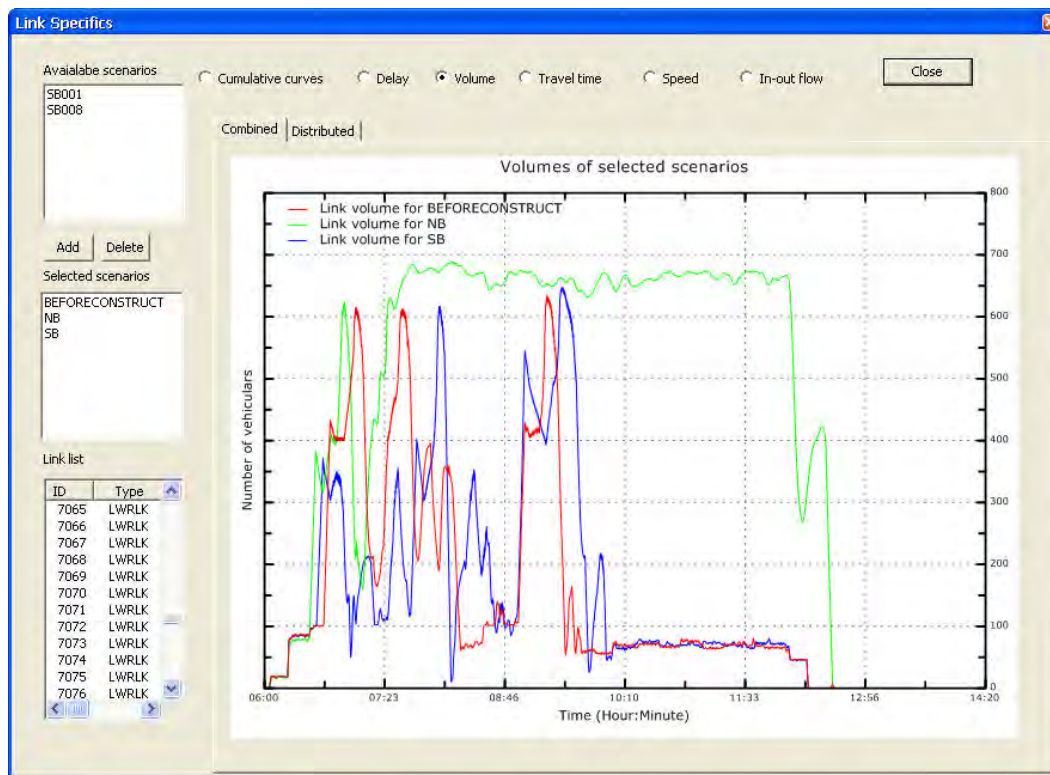


Figure 8.7: The time-dependent volume plot on Link 7068 for SB closure

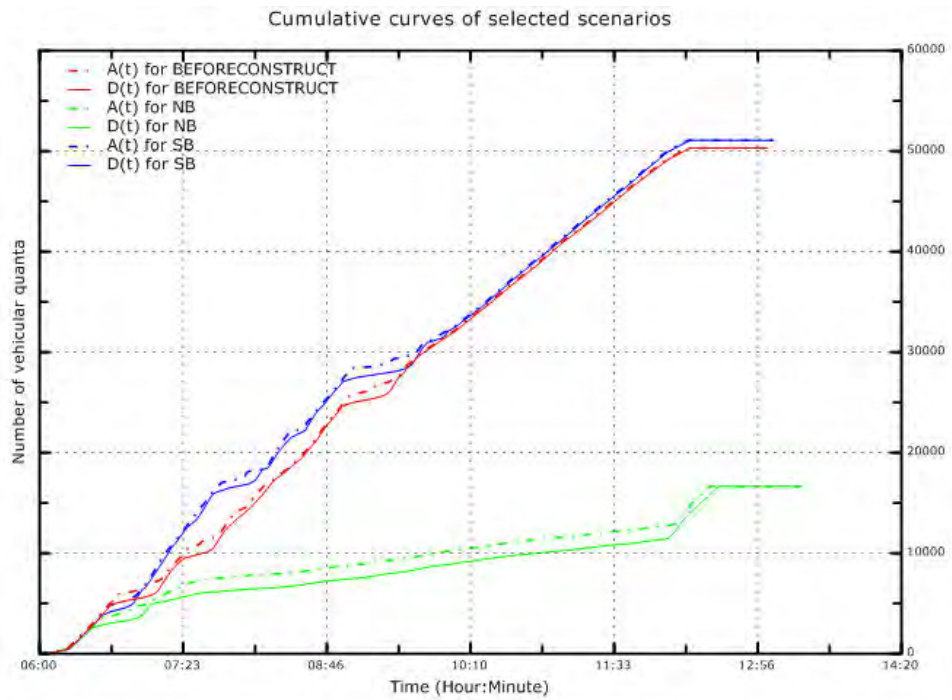


Figure 8.8: The cumulative curves on Link 7068 for SB closure

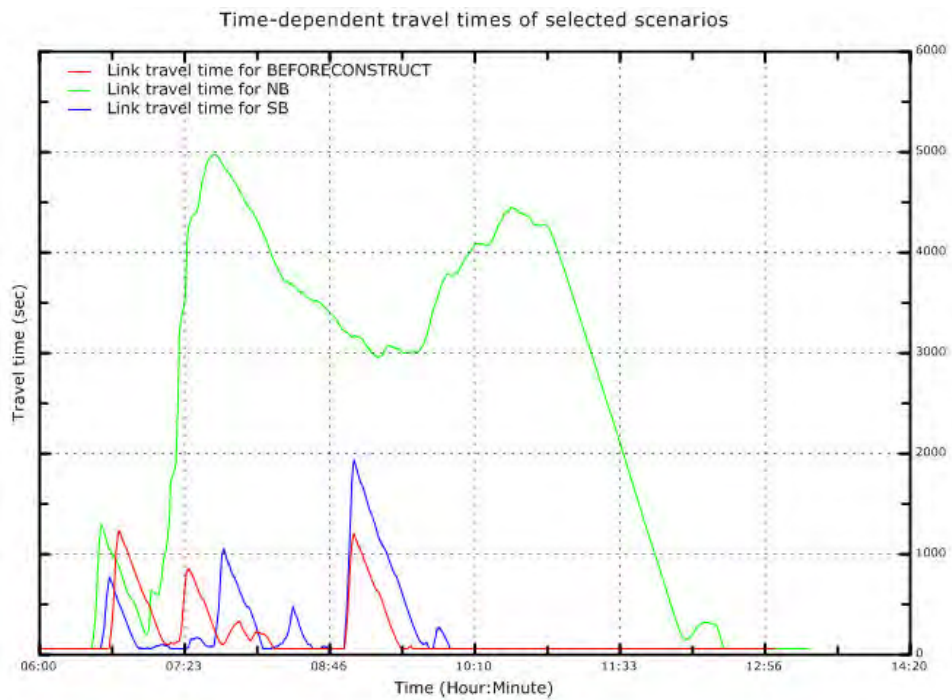


Figure 8.9: The time-dependent traversal time on Link 7068 for SB closure

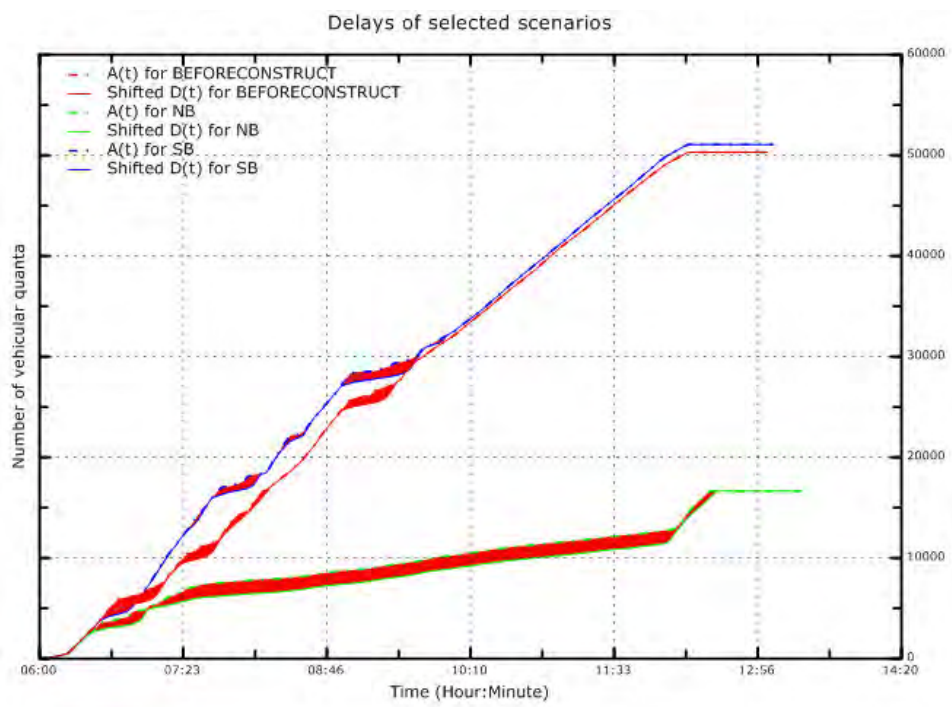


Figure 8.10: The time-dependent delay on Link 7068 for SB closure

Chapter 9

Conclusions

We implemented in **NetZone** a more realistic routing choice model and new work zone models that can be applied to evaluate more general work zone schedules. We also included HOV lanes and used the system performance of HOV travelers as one of the indicators to evaluate work zone plans. A new O-D connector model helps reduce the artificial congestion on the links adjacent to connectors, and it also can effectively prevent gridlock from occurring in some cases. The traffic signal control component in **NetZone** has been reorganized and further expanded to accommodate more traffic control options and strategies. The new **NetZone** now provides vehicle actuated control, stop-sign and yield-sign controls at intersections, signal coordinations between adjacent intersections/ramps, pre-timed ramp metering and traffic signal schemes by time of day. The emission module was also added in **NetZone** to calculate the fuel consumption and the emissions of the network during the analysis time period.

Beside the underlying models, we also reorganized and upgraded the graphical user interface (GUI) of **NetZone**. We improved the appearance of the software and meanwhile added more functionalities to the data visualization. New dialogs and windows were designed for new **NetZone** models. In addition, the improvement in computational efficiency was discussed. We fixed numerous programming bugs in **NetZone**.

In a nutshell, **NetZone** is a dynamic network analysis tool capable of estimating network-wide traffic impact for any general networks consisting of freeway, arterials and local streets. The new **NetZone** comes with the following features,

- **Representations of general networks:** this includes various types of roads and junctions, such as freeways, arterials, signal controlled intersections or metered ramps. This newer version of **NetZone** also added the capability of modeling High Occupancy Vehicle (HOV) facilities.

- **Added capability of modeling environmental impact:** the new NetZone implements speed based emission and fuel consumption models that can directly produce link based or network wide emission and fuel consumption statistics for several pollutants, such as HC, CO, CO₂ and NO_x.
- **Increased capabilities of modeling traffic control and demand management:** the new NetZone now has a more robust module to model various types of traffic control actions, such as pre-timed intersection signal timing and ramp metering, signal coordination, adaptive traffic control (vehicle actuated control and ALINEA ramp metering), and adaptive control integration (locally synchronized control or LSC). It also models the pairwise or overall traffic demand reduction induced by traveler information.
- **State of the art dynamic traffic model:** the new NetZone implements the classic macroscopic kinematic wave traffic flow model and state of the art junction models. It introduces a hybrid routing strategy where travelers separate into two groups, those who stick to their routes (habitual travelers) and those who change their routes in response to changing traffic conditions (adaptive travelers). The ratio between habitual and adaptive travelers can be adjusted/calibrated to capture the degree of traffic diversion and obtain realistic simulation results.
- **Streamlined data preparation and model calibration:** the new NetZone provides several options to prepare a network and its data related to a work zone project and various study scenarios. Most often, one can directly import a network from mainstream GIS software, then edit/change the network and its data with an easy-to-use graphical user interface. In particular, it comes with a state-of-the-art OD estimation module that helps users to obtain time-dependent OD demands, which often greatly shorten the calibration process. Several diagnostic tools, such as network connectivity and animation of traffic conditions through simulation replay, are also implemented to facilitate model calibration.
- **Powerful tools for project analysis and report generation:** NetZone provides several visualization tools to facilitate the analysis of project results. These include the cumulative flow diagrams, density/speed contour plots, link queuing/delay plots, and above all an animation tool showing 'live' traffic through re-playing simulation results, from which one can identify hot congestion spots. The animation tool is particularly useful during model calibration to spot problems such as gridlock.

- **Extensible framework:** NetZone actually has all the essential elements of a general purpose dynamic traffic assignment/simulation software and can be made to suit a variety of applications besides work zone studies. Examples include integrated corridor traffic management and environmental impact assessment of major transportation projects.

Furthermore, we present a case study, in which NetZone is used to assess the traffic impact of an actual work zone plan in a real large-scale network, i.e., the network of Sacramento Metropolitan Area with Fix I-5 work zone schedules. The case study demonstrates that NetZone is capable of dealing with realistic sizable problems, and the results are consistent with the real world. In addition, it is computationally efficient for large-scale networks. The Users' Manual and the tutorial will be provided in a separate document.

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