**Are we there yet? Automating and streaming traffic analysis tasks for integrated corridor management using a FOCUSING approach**

# Abstract

Motivated by a wide range of application needs, such as information elevation, complex multi-tasking in the traffic analysis has been increasingly recognized as a necessary process for assessing the operational performance of those applications. However, it is challenging to implement multiple complex processes in data collection, resolution and fidelity, modeling, and computation, especially in a full size of large-scale network. This paper develops a comprehensive practice-oriented automating and streaming workflow for traffic analysis tasks, called FOCUSING, which integrates 1) a **F**ocusing approach to define subareas, 2) **O**rigin-based flow extraction, 3) **C**olumn generation, 4) column **U**pdating path flow using multiple data sources, e.g. travel time and traffic counts, 5) **S**ensitivity analysis, 6) **I**nformation evaluation, 7) multiresolution **N**etwork, and 8) a**G**ent-based simulation. This framework aims to assist traffic engineers in 1) streaming the effectively complex multi-tasking for traffic analysis 2) automatically and efficiently executing traffic analysis workflow in large-scale networks on a computer with limited memory, 3) understanding advanced but sophisticated model structures, and 4) utilizing higher fidelity transportation measurement results to estimate and calibrate underlying transportation system processes under different traffic conditions.

Keywords: Focusing approach, Column generation, Sensitivity analysis, Simulation, Information evaluation

# Introduction

Increasing travel demand has created incident in urban traffic. From an operations perspective, integrated corridor management will increase agency awareness of incidents, develop enhanced real-time decision capabilities for advanced Transportation System Management and Operations (TSMO) strategy implementation, promote cross-agency information sharing, and provide advanced warning and alerts to travelers on the corridor to promote informed trip decision-making.

The traveler information systems are benefit from the data rich environment presented by the automobile navigation devices, such as the Global Positioning System (GPS). The data can be used to measure travel times and traffic flow distribution and evolution in the entire network. However, data processing and data calibration require innovative algorithm to reduce sensor installation, maintenance cost, and engineers’ efforts, also precisely estimate traffic conditions.

To assess the operational performance of those applications, the traffic analysis has been increasingly recognized as a necessary process. However, it is challenging to implement multiple complex processes in data collection, resolution and fidelity, modeling, and computation, especially in a full size of large-scale network. In addition, using computation models is an essential requirement for transportation planning and analysis processes. However, the large-scale transportation network poses a great challenge in terms of computational time and path storage space, especially when the time dimension is modeled since it will dramatically increase the number of efficient paths. Finding a complete set of solutions will be intractable. In addition, since there isn’t a unique model that can solve the various problems that planners or engineers may have because of complex time-varying interactions between the demand and supply side of a transportation network, there could be used very complex models. These models have to be executed in a reasonable time with operating a huge amount of data with uncertainty. Further, the impacted analysis for traffic response is challenging since drivers could be impacted by the information in the road. The summary of challenges is shown in **Table 1**.

From a practical point of view, in order to evaluate the safety, efficiency, and reliability of transportation systems, many traffic engineers, planners, and researchers have been working on data-driven calibration based on the Macroscopic Fundamental Diagram (MFD), and the integration of the simulation and optimization approaches in DTA problem to capture time-dependent congestion under the first-in-first-out

To increase the computational time, many researchers spend a lot of effort developing simulation models for rapid system modeling and analytics. Junchaya and Chang (1993) explored a parallel computing architecture that simulates a large-scale network with 32,000 vehicles within 312 minutes. Lee and Chandrasekar (2002) proposed a parallel traffic simulation computing framework to critically increase the simulation speed. Chen et al. (2011) developed an open-source traffic simulation package (QarSUMO) for parallel simulation and congestion optimization.

A number of generalized analytical approaches also have been provided. Cheng et al (2021) proposed an s-shaped traffic MFD to capture the relationship between speed and density under various possible densities. Pan et al (2022) analyze and highlight the connection between FD and queueing models, which are important to measure time-dependent delay performance under both undersaturated and oversaturated conditions. Along this line, Zhou et al. (2022) proposed a queue-based volume delay function within DTA model to measure and describe the time-dependent delay performance under the multiresolution model framework.

The Multiresolution model can be applied to the evaluation and analysis of different scenarios. Focusing on the large-scale regional strategy evaluation, the first two classes are more concerned about traffic flow propagation with less emphasis on detailed vehicle trajectories. On the other hand, microscopic simulation highlights detailed motion states of individual vehicles as well as interactions between different vehicles. In many large-scale projects, integrated modeling and simulation can be useful instead of multiple simulations. As such case of large-scale projects requires initial planning evaluation at the macroscopic level and evaluation process of design and operational alternatives at the microscopic level.

While previous studies in the areas of subarea analysis have made important contributions, in various aspects, there are still critically important research needs.

1. Automation of workflow

"Simplicity is a prerequisite for reliability." said by Edsger Dijkstra. The complex processes of traffic analysis could bring uncertainty and instability to the real-time decision. A streamlined and automated workflow is critical needed.

1. Data-driven calibration

A real-time calibration should be included in the space-time traffic simulation process (Henclewood et al., 2012). However, one of the challenges to be addressed is to build a computationally efficient and precise calibration model to deal with millions of real-time input data, such as speed, demand, congestion duration, and volume.

1. Transportation systems models

Scalability

To facilitate traffic analysis at a finer-grained level, the complexity of large-scale network molding and computation should be reduced.

Resolutions and Fidelity

Resolution is the degree of detail and precision used in the representation of real-world aspects in a model or simulation (Army Modeling and Simulation Office 2020). Fine-grained spatial resolutions make corridors, roads, and lane representation possible.

Integrated macroscopic and mesoscopic models

Traditionally macroscopic models have been used most frequently due to wider availability and lower computation times compared to mesoscopic and microscopic models. Mesoscopic simulation models aim to fill the gaps between the aggregate level approach of macroscopic models and the individual interactions of the microscopic ones. Although microscopic models provide more fidelity than mesoscopic models, the integrated macroscopic and mesoscopic models provide much better computational and modeling efficiency.

1. Path flow-based integrated equilibrium and re-assignment

For the impact analysis for traffic response and decision support, the path-flow based equilibrium and re-assignment should be utilized in understanding the impact of real time information provision and management strategies. The quality of the path flow, which depends on the calibration of MFD within the DTA module, will impact the results of path flow, such as the agent trajectory and time-dependent profile (Zhou et al., 2022).

It is critically important to develop a comprehensive but automotive and streamlined application workflow. Along this line, it is proposed to address the following research questions in this paper.

1. This paper will adopt the focusing approach and MRM framework to consider the affected areas at different resolutions.
2. This paper adopts the data-driven approaches to ensure other link volume and other observation constraints. Data-driven calibration and optimization models also provide priority strategies for planners and operators.
3. This paper will model the physical network and space-time network to analyze the impacts based on link level and path level. We also focus on column generation to manage a large number of variables and the interaction between them.
4. This paper will adopt the problem decomposition approach from mathematic programming, primal and dual decomposition to the practice. In addition, we will propose a mathematical method of picking the impacted OD pairs from simple geometry-based computing to reduce the degree of variable size to speed up the computational time in large-scale problems.

**Table 1** Challenges, solutions, and highlights in this paper

|  |  |  |
| --- | --- | --- |
| Challenges | solution | Highlight |
| Complex processes in real time decision | Streamline workflow and tool automation | Simplicity and reliability in model |
| Model complexity:  Challenges in resolution and fidelity: macro, meso, micro  Traffic Flow,  Cost-benefit analysis for real time information  Simulation | MRM: Integrated macroscopic and mesoscopic | Balance between representation details and computational efficiency |
| Scalability and computational challenges | Focusing approach | Fast execution |
| Data uncertainty | Integrated data driven approach + combination of data sources: statewide model, OSM model | Reliability in estimation |
| Impact analysis for traffic response: and decision support | Path flow based integrated equilibrium and re-assignment to understand the impact of real time information provision and management strategies | Seeing is believing (as a result of streamlined workflow) |

The rest of this paper is organized as follows: the next section reviews the proposed approaches, then states the problem and describes the mathematical model, and illustration for each stage in the proposed workflow, followed by a section that presents the experimental results, which are obtained via the open-source simulation environment; a final section concludes the paper, discussing results and opening for future investigations.

# Literature review and illustrations of the proposed approaches

In recent years, many methods have been proposed in the literature for traffic subarea analysis in terms of the applications of network assignment and simulation, namely in two categories, windowing and focusing approach, as **Fig. 1** shown. Compared with the windowing approach which considers the isolated subarea (Larson et al., 2001), the focusing approach includes external areas in addition to detailing trips and networks within the subarea (Haghani and Daskin, 1984), and then it performs the analysis with modified trips intact between the external and subarea. Along with this approach, Haghani and Daskin (ref) aimed to develop an aggregated network extraction algorithm by eliminating the links based on optimal user equilibrium. In another study, Hearn (1984) introduces the transfer decomposition method using an induced OD matrix, by partial assignment into subproblems and master which uses an abstract network. After a couple of years, Barton et al. (1989) proved that the proposed transfer decomposition method in Hearn (1984) is the same as the generalized Benders decomposition of the traffic assignment problem.

Chart

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**Fig. 1** Windows approach and focusing approach

MRM networks can be automatically generated by the osm2gmns package for any given network that meets the GMNS standard (Lu and Zhou, 2022), to accommodate different modeling needs. Figure shows the different representations of macroscopic, mesoscopic, and microscopic transportation networks.

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**Fig. 2** Multiresolution representation for signalized intersection

There are a number of studies focusing on the path flow-based problems. For linear and mixed integer programming path flow-based problem, column generation are widely used (Barnhart et al., 1998). Dumas et al. (1991) applied a column generation scheme with a shortest path problem with tight vehicle capacity constraints, and a small size of requests per route. Ropke and Cordeau (2009) presented a new branch-and-cut-and-price algorithm in which the lower bounds are computed by the column generation algorithm and improved by introducing different valid inequalities to the problem. Lu et al. (2009) proposed a column generation-based framework which generates generate a candidate path set that has competitive travel times to solve an undifferentiable cost function. Larsson et al. (2004) focused on the side constrained traffic equilibrium problem, which is solved by column generation based on their disaggregate simplicial decomposition (DSD) approach. Liu et al. (2020) build a column pool with projected gradient method to solve the proposed path flow-based linear programming model.

# Problem statement and mathematic models

Consider a physical transportation network with a finite set of nodes and a finite set of links where nodes and directed link . Let be a space-time network, where is the set of space-time vertexes and is the set of space-time links/arcs under the planning time horizon . Each arc indicates a directed space-time path from node departing at time to node arriving at time .

The notations used in this link-based model (**Model A**) and path-based model (**Model B**) are listed in **Table 2**.

**Table 2** Basic indices used to describe the space-time modeling framework

|  |  |
| --- | --- |
| **Index** | **Definition** |
|  | Physical transportation network |
|  | Space-time transportation network |
|  | OD pairs on the physical network |
|  | Path on the physical network, |
|  | Earliest departure time of vehicle |
|  | Latest arrival time of vehicle |
|  | Origin zone, |
|  | Destination zone, |
|  | Index of space-time traveling arc for the pair, |
|  | Link travel time from node to node starting at time |
|  | Link free flow travel time from node to node |
|  | Road capacity from node to node starting at time. |
|  | Specific transportation cost on arc , including transportation costs, vehicle waiting time, converted through drivers’ values of time |
|  | Flow of the link after running the entire network |
|  | Demand between OD pair , |
|  | Cost of path between OD pair , |
|  | Traffic flow of path between OD pair , |
| **variables** | **Definition** |
|  | Vehicle routing variable (=1, if physical arc () is selected; =0, otherwise) |
|  | Vehicle space-time routing variable (=1, if space-time arc () is selected; =0, otherwise) |
|  | Path variable (=1, if path is selected; =0, otherwise) |
|  | Link variable (=1, if path go through physical arc (); =0, otherwise) |

Under the assumption of discretized space-time network structure and constant bottleneck discharge rate, the vehicles’ speed in undersaturated and oversaturated conditions is easy to be estimated. Lu et al. [26] provides the comparison study of the point queues, spatial queues, and an extended version with time-dependent capacity and spillback. Along this line, a space-time network and agent-based model (**Model A**) and path-based model (**Model B**) can be built systematically using the steps from Tong et al. [28]. The schematic trajectories of from node to node in the space-time network are shown in **Fig. 3**.



**Fig. 3** Vehicle trajectory from node to node with a bottleneck in space-time network (adopted from Lawson et al. [27] )

**Model A: Agent-based optimization model**

The **objective function** shown in Eq. (1) is to minimize all vehicles' total costs.

|  |  |
| --- | --- |
|  | (1) |

Flow balance constraints for **physical path** at vehicle node

|  |  |
| --- | --- |
|  | (2) |

Flow balance constraint for **space-time path** at vehicle vertex

|  |  |
| --- | --- |
|  | (3) |

Consistency constraints **between physical arc and space-time arc**

|  |  |
| --- | --- |
|  | (4) |

**Road capacity** constraints for all the vehicles using the same **space-time arc**

|  |  |
| --- | --- |
|  | (5) |

Eqs. (2) and (3) proposed flow balance constraints in physical network and space-time network. Eqs. (4) ensure the consistency between arcs of physical network and space-time network. The constraint (5) can be viewed that all the vehicles in arc should less than the arc capacity. The related modeling details can be found in Lu et al. [26].

**Model B: Path-based optimization model**

The **objective function** shown in Eq. (1) is to minimize all paths' total costs.

|  |  |
| --- | --- |
|  | (6) |

Flow balance constraints

|  |  |
| --- | --- |
| , ∀*o*, *d* | (7) |

Link flow= sum of passing path flow

|  |  |
| --- | --- |
|  | (8) |

link travel time = QVDF of link volume

|  |  |
| --- | --- |
|  | (9) |

path travel time = sum of link travel time

|  |  |
| --- | --- |
|  | (10) |

**Road capacity** constraints for all the path passing through the same **space-time arc**

|  |  |
| --- | --- |
|  | (11) |

Positive continuous variable

|  |  |
| --- | --- |
| , ∀ *o*, *d*, and *p*∈*P* (*o*, *d*) | (12) |

Eqs. (7) impose flow balance constraints in physical network. Eqs. (8) means that the total flow of arc the path passing through should be the same as the flow of arc . Similarly, the travel time of path should be the total travel time of arcs which belongs to the path, as Eqs. (10). The link travel time can be calculated by the Queue-based Volume Delay Function (QVDF) (Zhou et al, 2022), as Eqs. (9) shown. Eqs. (11) shows the road capacity constraints.

# FOCUSING Workflow

**Table 5** Illustration for each stage of FOCUSING approach

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Steps | Input | Process | Output |
| F | Focusing approach | subarea.csv | 1. Identify subarea  2. Reduce the OD size:  Identify the internal zones.  Identify important external related zones outside the subarea. The importance of zones is decided based on the total amount of  OD volume passing through the subarea. | subarea\_related\_zone.csv  each zone has a district id automatically identified |
| O | Origin-based flow extraction |  | Reduce the OD size further. |  |
| C | Column generation and updating |  | Generate different paths |  |
| U | Baseline assignment and OD estimation | Measurement  (traffic counts inside subarea) | Perform column generation, and column-based updating as a nonlinear program for ODME to minimize the total deviations assigned volume and traffic counts. | observed and assigned link volume in  link\_performance.csv  before MOEs (Volume, speed, D/C, congestion duration P) |
| S | Subarea based sensitivity analysis | supply\_side\_scenario  (# of lanes being changed to represent work zone or incident)  or  demand\_side\_scenario | 1. Change the number of lanes from the baseline result,  2. Perform column generation again to find alternative routes,  3. Perform column updating to reach a new user equilibrium link and route flow | final\_summary.csv  link\_performance.csv  **subarea\_link\_performance.csv**  (volume, speed, D/C ratio, congestion duration for each link. Before and after the scenario being applied)  corridor\_performance.csv  **district\_performance.csv** (total travel time, average distance, and average travel time for each district) |
| I | Information classes | Real time, DMS, DMS + mandatory information | Specify the DMS location | Travel time for each information users |
| N | Multiresolution network | Macroscopic network form OSM | Osm2gmns python package | Mesoscopic and Microscopic network |
| G | Agent-based Simulation | supply\_side\_scenario or  demand\_side\_scenario |  | before and after MOEs in  link\_performance.csv and corridor\_performance.csv |

**Stage FO: OD size reduction**

The key goal of this stage is to find an appropriate zone set, called subarea related zone, to run the DTA model so that we can minimize the gap of the link volume inside the subarea after we reduce the zone size, called after link volume for convenience, and the corresponding link volume when we solve the entire statewide network, called original link volume. At the same time, the computer memory use can be reduced and the computation efficiency can be improved.

We suppose a zone set, W, containing all zones of the entire network, and a zone set, S, with subarea related zone we final choose. I is the internal zone set of the subarea, E is the external impact zone set of the subarea, and Y is the unrelated zone set. Thus, W=I+E+Y. Obviously, all zones in I should be chosen for S. EA and EB are chosen as an unchosen external impact zone to S, respectively. Thus, S=I+EA.

Diagram

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**Fig. 4** Zone set structure in subarea related zone

When we run DTA based on the entire network, that is all zones are chosen to S, where Y is an empty set, EA = E+Y. In addition, the gap between the after link volume and the original link volume is 0. The original demand matrix is combined by sets of I, EA, EB, and Y, as **Table 3** shown. Therefore, the errors are from the zones which are mainly in EB.

**Table 3** The source of the approximation error

|  |  |  |  |
| --- | --- | --- | --- |
|  | I | EA | EB |
| I |  |  | error source |
| EA |  |  |  |
| EB | error source |  | error source |

The gap can be calculated by the following formulation:

Difference = after volume – original volume

This paper use the straight line approximation. If an OD pair straight line is passing through the polygon of the subarea, then it is defined as impacted OD pair. If an origin zone has no significant impact total volume from this zone, it is determined as insignificantly impacted zone. Then we sort the impacted zones according to its impacted volume and only keep a small import set for focused assignment.

**Stage CU: Column generation and updating**

We proposed an approximation approach to study a relatively small, focused subarea with more complex traffic conditions, so that we can clearly calculate the mutual impact between each vehicle group and space-time paths from a system with sampled vehicles and reduced link capacities.

A space-time-state path of one vehicle with served passengers and visited space-time arcs is called one column in the column pool. The more columns we can build in advance, the more candidates we can choose to satisfy passengers’ requests and road capacity by vehicle flow assignment. Different vehicles from the same group could serve different passengers from different passenger groups and also visit different arcs, so we can have more relations among vehicle groups, passenger groups, and space-time arcs. Then, based on the real-world passenger requests and road capacity, we will determine how to reach the minimal system travel cost under arc capacity constraints.

**Stage S: Sensitivity analysis**

This stage is to analyze the performance measurement before and after the scenarios. The key input of sensitivity analysis is the OD demand matrixes for base year and future year. Then perform column generation again to find alternative routes after applying demand-side or supply-side scenarios. Future we will perform a column updating step to reach a new user equilibrium link and route flow. Finally, the output will be the time-dependent volume and speed, congestion duration, and congested demand volume.

**Stage I: information classes**

Incident response operations require effective planning of resources to ensure timely clearance of roadway accidents and avoidance of secondary incidents. For quick access to incident sites, it is important to make strategic decisions on the dispatching location of patrol cars considering their availability. This study formulates a mixed- integer linear model that minimizes the total expected travel time and maximizes the total incident demand covered. The model accounts for the location, severity, frequency of incidents, dispatching locations, and availability of incident respon- dents. An integrated methodology is proposed that includes column generation and Lagrangian relaxation along with a density-based spatial clustering of applications with noise technique to define incident hotspots. A Benders decomposition technique is implemented to conduct benchmark analyses. The integrated solution technique is applied to an empirical case study in Raleigh, NC. A network instance with 10,672 incident sites, clustered with a search distance (𝜖) of 5𝑚𝑖𝑛, is solved very efficiently with an optimality gap of 1.37%. The numerical results suggest that the solution algorithm can solve the problem efficiently and outperform the benchmark solutions.

In this scenario, there are three types of travelers (user with different information):

* No Information\historical knowledge: users will not deviate from typical routes
* Pre-trip real time information: Users choose alternative routes when they depart.
* Dynamic Message Signs (DMS): location-based information provision: Users can change routes at various VMS points along the way.

Illustrative examples of route choices of users with different information are provided in **Fig. 4**.

Diagram

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(a) route choice of users with pre-trip information

Diagram

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(b) route choice of users with en-route and historical information

**Fig. 4** Route choice of users with different types of information

**Stage N: multiresolution network**

To enable seamless data exchange among models of various domains and scales, the research team utilizes and enhanced a GMNS-based data hub by FHWA. <https://github.com/zephyr-data-specs/GMNS>. To model intersection turning movements and signal control well, the research team proposed a Multi-Resolution Model (MRM) methodology and workflow. In MRM, the analyst simultaneously assesses traffic performance at multiple resolutions: macroscopic, mesoscopic, and microscopic. A planning agency can start from a developed state-wide or regional macroscopic model, perform a more detailed (e.g., mesoscopic simulation-based dynamic traffic assignment (DTA)) analysis of a subregional area, and then perform an even more detailed (e.g., microscopic simulation) analysis of a corridor or facility. For the subarea analysis, the research team uses a focusing approach to build a hybrid-resolution network with the complete traffic analysis zone structure and high-fidelity meso or microscopic representation for the subarea. For the freeway or corridor level, the research team calibrates critical traffic stream parameters based on observed speed and volume data and then performs a cellular automata-based microscopic traffic simulation. **Table 4** shows the representations for different resolution model.

**Table 4** Representation of modeling and scenario for multiresolution models

|  |  |  |
| --- | --- | --- |
| Spatial resolution | Modeling | Scenarios |
| Macro node + movement+ segment data | Link-based queue | Adding/subtracting lanes, closing segments |
| Meso movement link based | Link-based queue, movement-specific | Signal timing control, movement capacity control at link level |
| Micro cell based | Lane-based queue, consider complex lane changing behavior | Signal timing control, lane choice |

**Fig. 5** shows the network of interest extracted from OpenStreetMap using osm2gmns. The osm2gmns is used to convert the macroscopic network to the corresponding mesoscopic network. Compared to macroscopic networks, mesoscopic networks have more detailed movement information within intersections. **Fig. 6** shows the comparison between a macroscopic and mesoscopic representation for a four-leg intersection.

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**Fig. 5** Network from OpenStreetMap using osm2gmns

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**Fig. 6** Comparison between macroscopic and mesoscopic representation for a four-leg intersection

**Stage G: Agent-based simulation**

Agent-based modeling and simulation (ABMS) is a modeling approach for simulating the actions and interactions of autonomous individuals, assessing their effects on the system as a whole. The basic idea of ABMS is that complex phenomena can be understood as systems of autonomous agents following rules of interaction. In contrast to the traditional event simulation, which assumes that entities follow a sequence of processes, ABMS defines the local behavior rules of the underlying entities to reveal the emerging behaviors of the whole system. ABMS is widely used in modeling human social and organizational behavior and individual decision making (Zheng et al. 2013).

# Numerical experiments

This section excutes Loop 101 numerical experiment of integrated corridor management with incident scenario to evaluate the proposed FOCUSING approach in terms of solution quality, information evaluation, and computational performance. The cases are implemented on a computer with 2.80 GHz CPU and 16 GB of memory.

We assume the incident 1) occurs during morning peak hour, 2) occurs east of 51st Ave. and west of 43rd Ave, and 3) leads to full freeway closure and lasts 3 hours. **Fig. 7** presents all alternative routes to avoid the incident area on loop 101 (21 routes in total).

Table

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**Fig. 7** Summary of all alternative routes

## Scenario – Do Nothing

General ideas for traffic simulation in the do-nothing scenario:

* Agents will re-route themselves if (1) their “normal” paths are affected by the closure, (2) when they get close and “see” the congestion caused by the closure.
* Re-routing is based on current instantaneous travel time.

**Fig. 8** provides the simulated traffic states at different times (8 am, 9 am, and 10 am).

A picture containing timeline

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(a) Traffic state at 8 am (b) Traffic state at 9 am

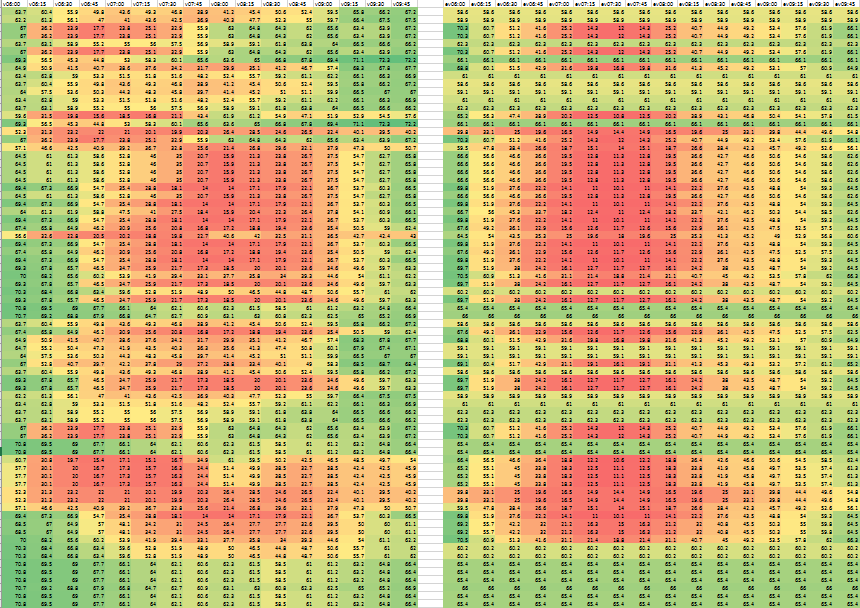
Diagram

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(c) Traffic state at 10 am

**Fig. 8** Simulated traffic states at different time

**Fig. 9** presents the comparison between observed speed and DTALite modeled speed on the AZ-101-LOOP-EASTBOUND. As can be seen, in the baseline scenario, the modeled speed is very close to the observed speed on the 101 Loop, showing the capability of DTALite for accurately simulating traffic flows.



**Fig. 9** Comparison between observed speed and DTALite modeled speed

As examples, the time-dependent observed speeds and modeled speeds of three segments on loop 101 are further presented in **Fig. 10**.

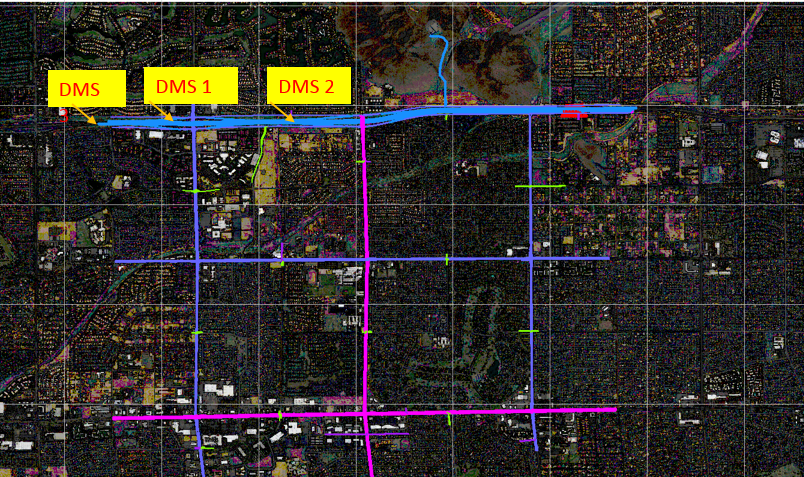
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**Fig. 10** Time-dependent observed speeds and modeled speeds on three segments.

## Scenario - Integrated Corridor Management (ICM)

In this section, the results of traffic incidents with integrated corridor management (ICM) are provided. As shown in **Fig. 11**, three dynamic message signs (DMSs) are located upstream of the incident area to evaluate the effect of ICM.



**Fig. 11** The focused network with DMSs

**Table 6** provides the summary of simulation results with different settings of DMS.

**Table 6** Summary of simulation results

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Traveler info Type** | Baseline  Case 0  Travel Time (min)  15% RT Info | ICM Case 1: 2 DMS  Travel Time | ICM Case 1: 2 DMS  Travel Time Reduction | **Percentage of Difference** | ICM Case 2: 50% RT info  Travel Time | ICM Case 2: 50% RT info  Travel Time Reduction | **Percentage of Difference** |
| Regular (with visual distance) | 68.27 | 67.88 | -0.40 | -0.58% | 64.40 | -3.48 | -5.12% |
| RT info | 54.74 | 53.33 | -1.41 | -2.57% | 55.67 | 2.34 | +4.38% |

# Conclusion

This paper proposed the FOCUSING framework for automating and streaming traffic analysis tasks for integrated corridor management. This framework integrates 1) the focusing approach and 2) origin-based flow extraction to reduce the zone size so that reduces the scale level of the path flow-based traffic assignment problem, 3) the column generation and 4) updating which generate the path flow and link flow according to the UE principle, 5) sensitivity analysis to evaluate the difference of MOEs before and after each scenario, such as lanes adding and enclosure, work zone, incidence, signal timing plans, and multi-modal service plans, 6) information evaluation, 7) multiresolution network, and 8) path-based simulation which utilizes the path flow output of dynamic traffic assignment to measure time-dependent queue-based speed, congestion duration and delay calculation. Compared to the traditional framework for large-scale problems, this framework can help traffic engineers, planners, and researchers precisely and quickly evaluate different scenarios on a computer with limited memory. The benefit can be certificated by the three different scale case studies. The Loop 101 examples illustrate the implement traffic analysis process for integrated corridor management with incidence scenarios.

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