Technical University of Crete
School of Production Engineering and Management
Dynamic Systems and Simulation Laboratory

Freeway Traffic Flow Modeling and Control with Emphasis on Congested Off-Ramp Areas

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Calibration of Macroscopic Traffic Flow Models

Real-Time Traffic Control Measures : Case 1 – Route diversion control

Real-Time Traffic Control Measures : Case 2 – Merging traffic control

Conclusions and Future Work

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Calibration of Macroscopic Traffic Flow Models

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- Motivation
- Objectives and Approach

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Conclusions and Future Work

Introduction

Motivation

- During the last decades, freeway congestion has been a major problem especially at urban freeways and peri-urban ring-roads.

- Recurrent traffic congestion is usually encountered at freeway on-ramp areas or freeway-to-freeway merging areas, but, quite frequently, also close to freeway off-ramp areas.

- Expanding the existing infrastructure is not always a feasible option, for economic and environmental reasons, thus traffic control has been employed as an efficient way to mitigate the problem of freeway congestion.

Introduction
Motivation

- Very limited technical literature (and practical systems) addressing appropriate control measures for congested off-ramp areas.
- The main reasons probably being that there is no direct way, from the freeway side, to control the freeway exit flow.
- The development of innovative traffic control measures requires the existence of accurate traffic flow models that are able to reproduce the traffic conditions at such areas with satisfactory accuracy.
- Although, a high number of traffic flow models has been proposed over the last decades, they have never been validated and compared for congested freeway off-ramp areas.

Introduction

Objectives and Approach

The objective of this research is twofold:

- First, it aims to identify suitable macroscopic traffic flow models that can represent the traffic conditions at congested freeway off-ramp areas with sufficient accuracy.

  Approach: The two most popular macroscopic traffic flow models are validated and compared using real traffic data from a freeway stretch in Athens, Greece, where recurrent traffic congestion is created due to a saturated off-ramp.

- Second, it aims to the develop innovative real-time traffic control measures for congested freeway off-ramp areas.

  Approach: Two different network topologies are examined, that are often encountered in reality, and suitable traffic control strategies are proposed for every case.

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Calibration of Macroscopic Traffic Flow Models

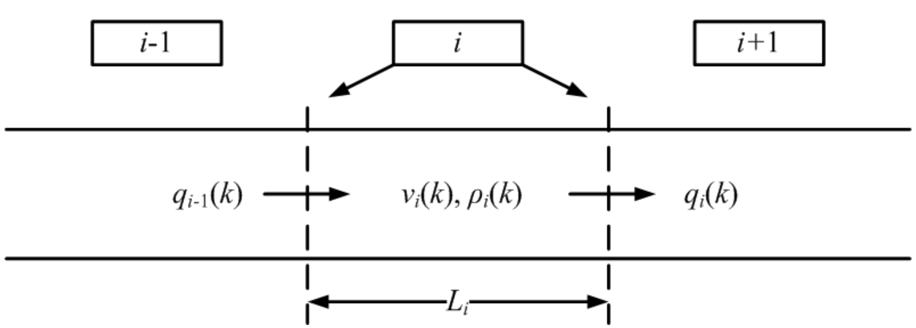
- Introduction
- Macroscopic traffic flow models
- Model calibration procedure
- Calibration and validation results
- Conclusions and remarks

Conclusions and Future Work

Introduction

- Macroscopic mathematical traffic flow models are useful tools for:
  - planning of new, or upgraded road infrastructures
  - development and testing of traffic estimation algorithms
  - development and testing of traffic control strategies
  - etc.
- The models include a number of parameters, whose values may differ for different freeway sites.
- Before employing a traffic flow model in practice, it is important to first calibrate it against real traffic data, i.e. to appropriately specify the model parameter values.
- This section calibrates, validates and compares two macroscopic models, regarding the reproduction of traffic conditions at a congested freeway off-ramp area.

Macroscopic traffic flow models:
CTM (Cell Transmission Model)



Model parameters:

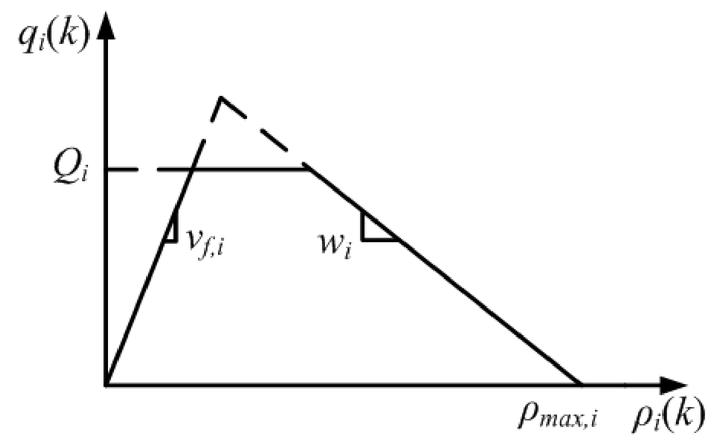
$v_{f,i}$:	free flow speed
w_i:	congestion wave speed
$\rho_{max,i}$:	maximum density
Q_i:	capacity flow

$$\rho_i(k+1) = \rho_i(k) + \frac{T}{L_i \lambda_i}\left[q_{i-1}(k) - q_i(k)\right]$$

$$q_i(k) = \min\{v_{f,i}\rho_i(k)\lambda_i, \bar{Q}, w_{i+1}\left[\rho_{\max,i+1} - \rho_{i+1}(k)\right]\lambda_{i+1}\}$$

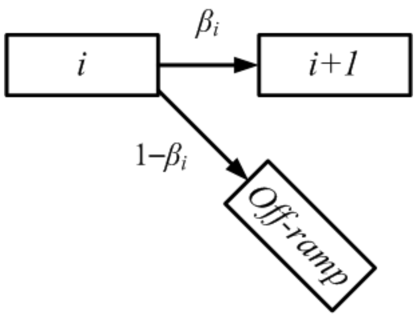
$$\bar{Q} = \min\{Q_i, Q_{i+1}\}$$

$$v_i(k) = q_i(k) / \left[\rho_i(k)\lambda_i\right]$$



Macroscopic traffic flow models:
CTM (Cell Transmission Model)

At bifurcations:



Model parameters:

$v_{f,i}$:	free flow speed
w_i:	congestion wave speed
$\rho_{max,i}$:	maximum density
Q_i:	capacity flow
$w_{off\text{-}ramp}$:	congestion wave speed (off-ramp)
$\rho_{max\text{-}off\text{-}ramp}$:	maximum density (off-ramp)

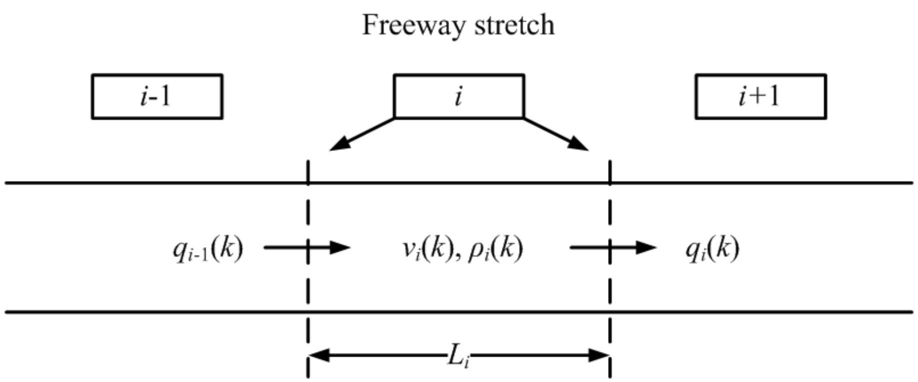
$$q_i(k) = \min\{S_i(k),\ R_{i+1}(k)/(1-\beta_i(k)),\ R_{off-ramp}(k)/\beta_i(k)\}$$

$$S_i(k) = \min\{Q_i, v_{f,i}\rho_i(k)\lambda_i\}$$

$$R_{i+1}(k) = \min\{Q_{i+1}, w_{i+1}\left[\rho_{\max,i+1} - \rho_{i+1}(k)\right]\lambda_{i+1}\}$$

$$R_{off-ramp}(k) = \min\{Q_{off-ramp}, w_{off-ramp}\left[\rho_{\max,off-ramp} - \rho_{off-ramp}(k)\right]\lambda_{off-ramp}\}$$

Macroscopic traffic flow models: METANET



$$\rho_i(k+1) = \rho_i(k) + \frac{T}{L_i\lambda_i}\left[q_{i-1}(k) - q_i(k)\right]$$

$$q_i(k) = v_i(k)\rho_i(k)\lambda_i$$

$$v_i(k+1) = v_i(k) + \frac{T}{L_i}v_i(k)\left[v_{i-1}(k) - v_i(k)\right] + \frac{T}{\tau}\left[V^e(\rho_i(k)) - v_i(k)\right] - \frac{vT\left[\rho_{i+1}(k) - \rho_i(k)\right]}{\tau L_i\left[\rho_i(k)+\kappa\right]}$$

$$- \frac{\delta T q_r(k) v_i(k)}{L_i\lambda_i\left[\rho_i(k)+\kappa\right]} - \frac{\varphi T \Delta\lambda \rho_i(k) v_i(k)^2}{L_i\lambda_i\rho_{cr,i}}$$

$$V^e(\rho_i(k)) = v_{f,i}\exp\left[-\frac{1}{a_i}\left(\frac{\rho_i(k)}{\rho_{cr,i}}\right)^{a_i}\right]$$

Model parameters:

$v_{f,i}$: free flow speed

$\rho_{cr,i}$: critical density

α_i: FD parameter

τ: time parameter

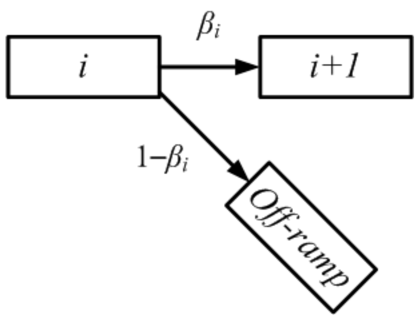
v: anticipation parameter

δ: merging parameter

φ: lane-drop parameter

Macroscopic traffic flow models: METANET

At bifurcations:



$$\rho_{v,i+1}(k) = \frac{\rho_{i+1}{}^2(k) + \rho_{off-ramp}{}^2(k)}{\rho_{i+1}(k) + \rho_{off-ramp}(k)}$$

$\rho_{v,i+1}$: virtual density downstream of section i

no parameters are included!

Model parameters:

$v_{f,i}$: free flow speed

$\rho_{cr,i}$: critical density

α_i: FD parameter

τ: time parameter

ν: anticipation parameter

δ: merging parameter

φ: lane-drop parameter

Model calibration procedure

$$\mathbf{x}(k+1) = f[\mathbf{x}(k), \mathbf{d}(k), \mathbf{p}] \qquad k = 0,1,\ldots,K-1$$
$$\mathbf{x}(0) = \mathbf{x}_0$$

x: state vector

d: disturbance vector

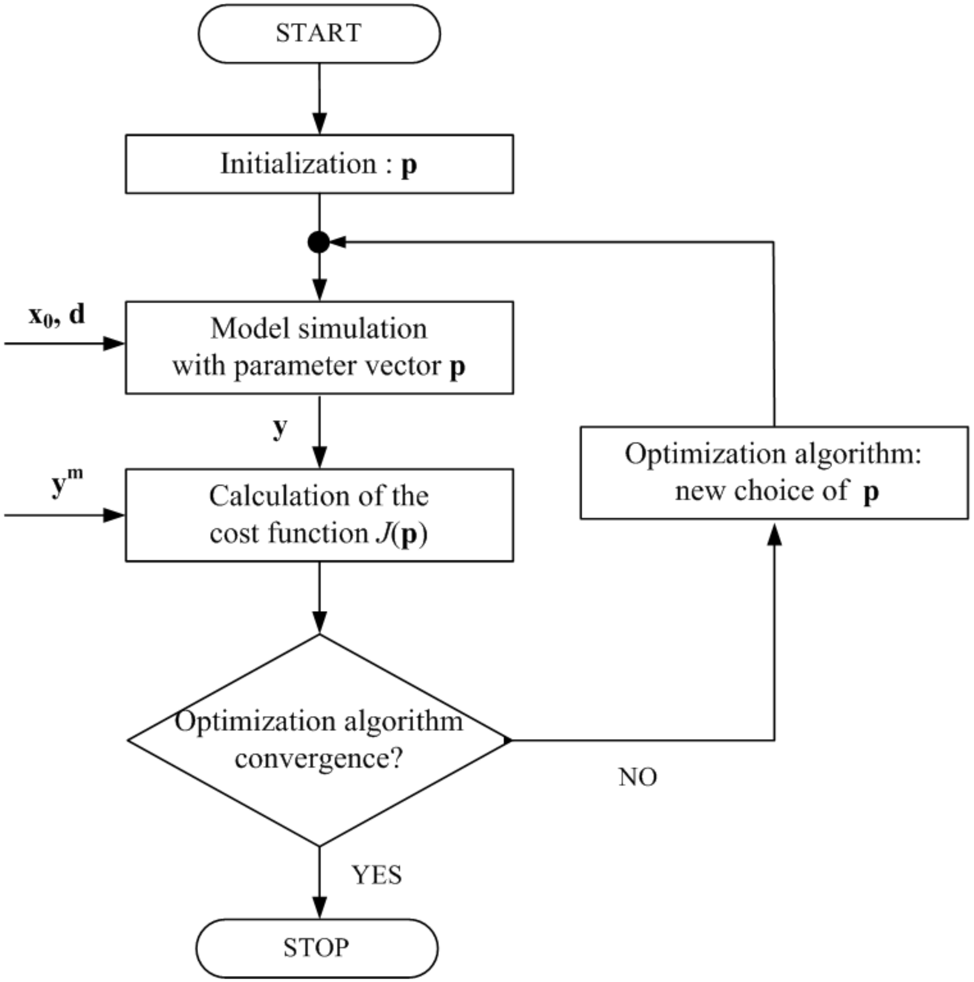
p: parameter vector

$$J(\mathbf{p}) = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\left[\mathbf{y}(k) - \mathbf{y}^{\mathbf{m}}(k)\right]^2}$$

$$\mathbf{y}(k) = \mathbf{g}[\mathbf{x}(k)]$$

y: model estimations

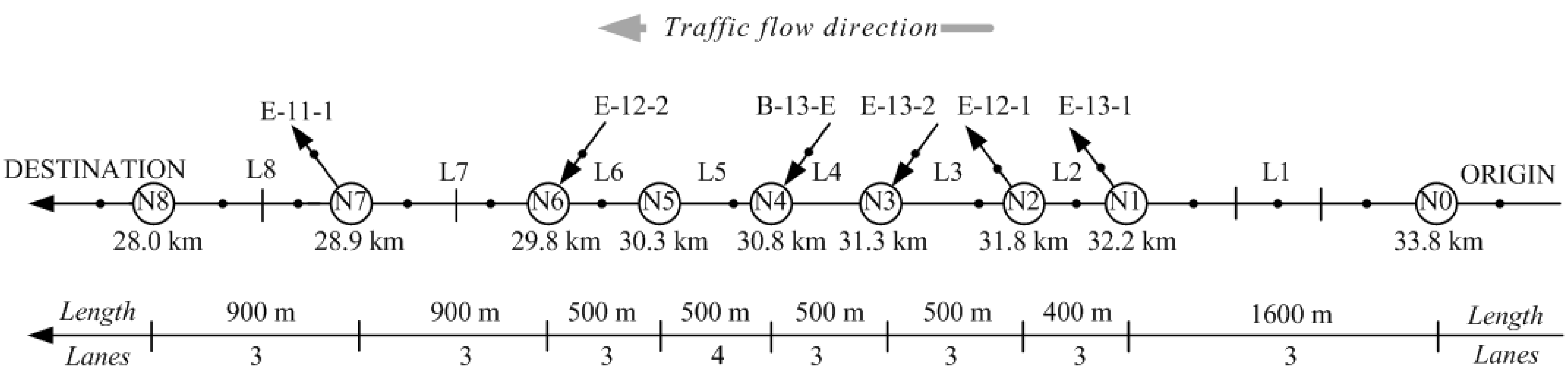
$\mathbf{y}^{\mathbf{m}}$: real measured traffic data



Calibration and validation results: Freeway site and real traffic data

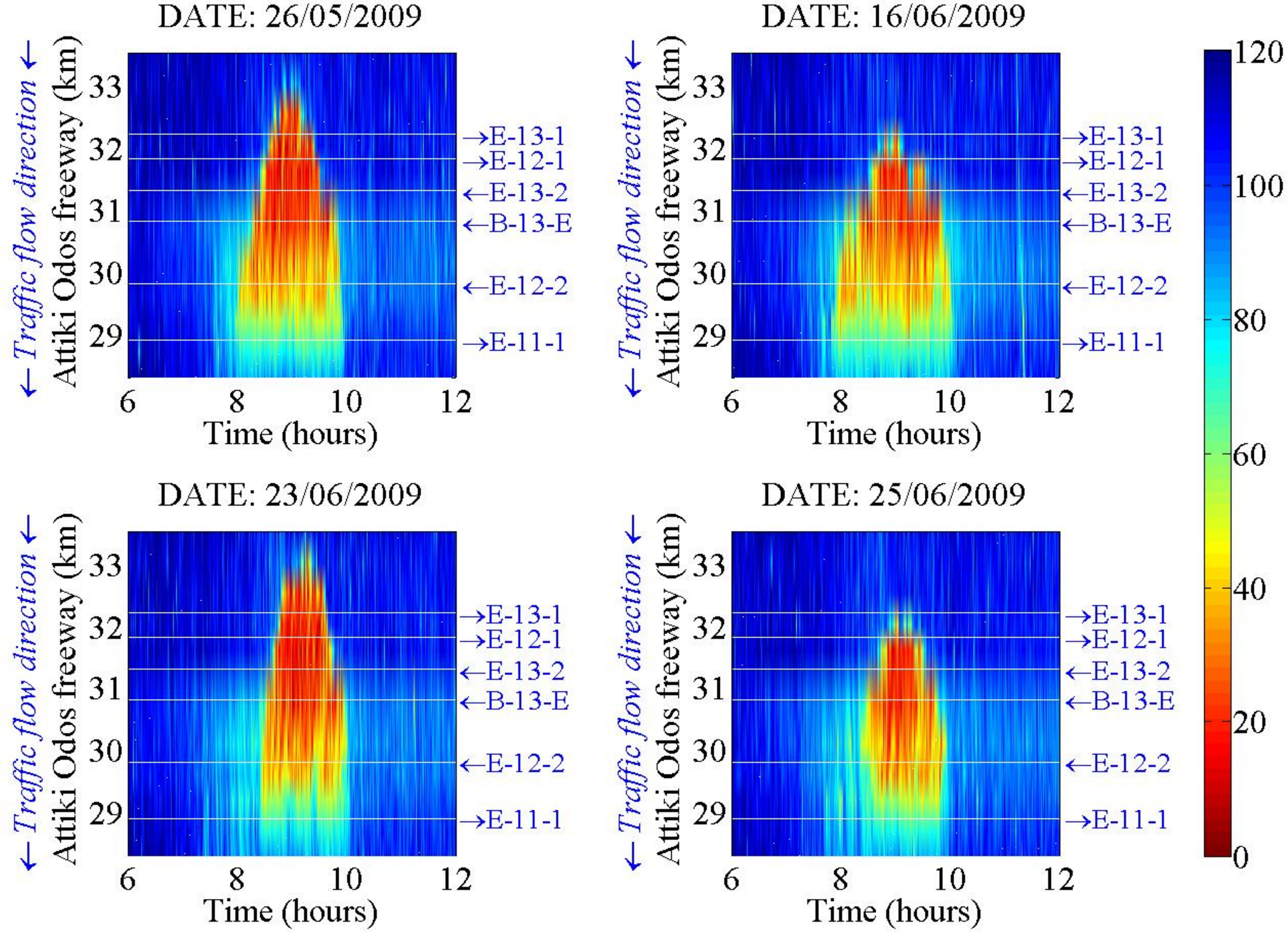
Attiki Odos freeway stretch:

~6 km long - 3 on-ramps - 3 off-ramps - 11 detector stations



Calibration and validation results:
Freeway site and real traffic data

Real traffic data:



Calibration and validation results:
Calibration settings

Simulation set-up:

- Models' time step: $T = 5$ s.
- CTM parameter vector: $\mathbf{p_1} = [v_f \;\; w \;\; \rho_{max} \;\; Q \;\; w_{off\text{-}ramp} \; \rho_{max\_off\text{-}ramp}]$.
- METANET parameter vector: $\mathbf{p_2} = [v_f \;\; \rho_{cr} \;\; a \;\; \tau \;\; \nu \;\; \delta \;\; \varphi]$.
- One single fundamental diagram is considered for all freeway sections.
- Real traffic data from 26/05/2009, 16/06/2009, 23/06/2009, 25/06/2009.
- Performance index (PI): RMSE of real versus estimated speeds.

Calibration and validation results:
Calibration settings

Calibration set-up:

- Three derivative-free optimization algorithms are employed:
  - Nelder-Mead algorithm
  - Genetic algorithm
  - Cross-entropy method
- Various calibrations tests were carried out for both models and only the best obtained results are presented in the following.

Calibration and validation results:
Models' calibration

CTM

Optimization method	Iterations	Cost function evaluations	Computation time (min)
NM	393	609	0.8
GA	71	36000	34.6
CE	37	18500	19.7

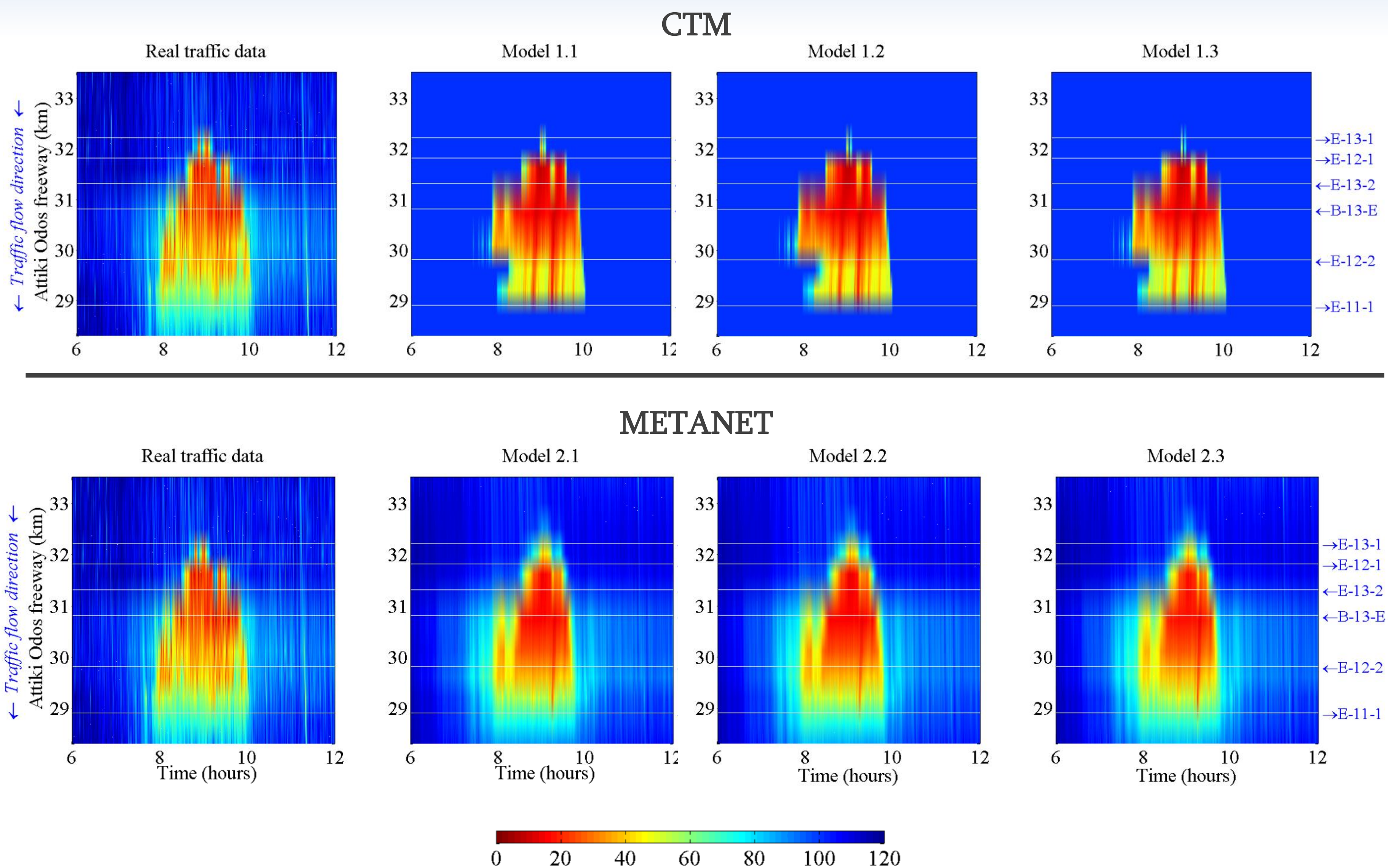
Model	CTM parameters					
	v_f (km/h)	ρ_{max} (veh/km/lane)	w (km/h)	Q (veh/h)	$\rho_{max\_off\text{-}ramp}$ (veh/km/lane)	w_{off_ramp} (km/h)
Model 1.1 (NM)	100.4	142.6	22.6	2273	126.3	19.7
Model 1.2 (GA)	100.3	148.9	21.5	2247	124.7	21.0
Model 1.3 (CE)	100.4	153.8	19.8	2268	123.5	20.5

METANET

Optimization method	Iterations	Cost function evaluations	Computation time (min)
NM	204	317	0.5
GA	51	26000	122.9
CE	85	42500	197.8

Model	METANET parameters						
	v_f (km/h)	ρ_{cr} (veh/km/lane)	a	τ (s)	ν (km²/h)	δ (h/km)	φ (h/km)
Model 2.1 (NM)	117.8	35.5	1.5	18.6	24.5	1.2	1.1
Model 2.2 (GA)	118.1	36.2	1.4	18.1	21.1	0.2	1.5
Model 2.3 (CE)	118.8	34.4	1.5	27.2	33.1	0.5	1.0

Calibration and validation results:
Models' calibration

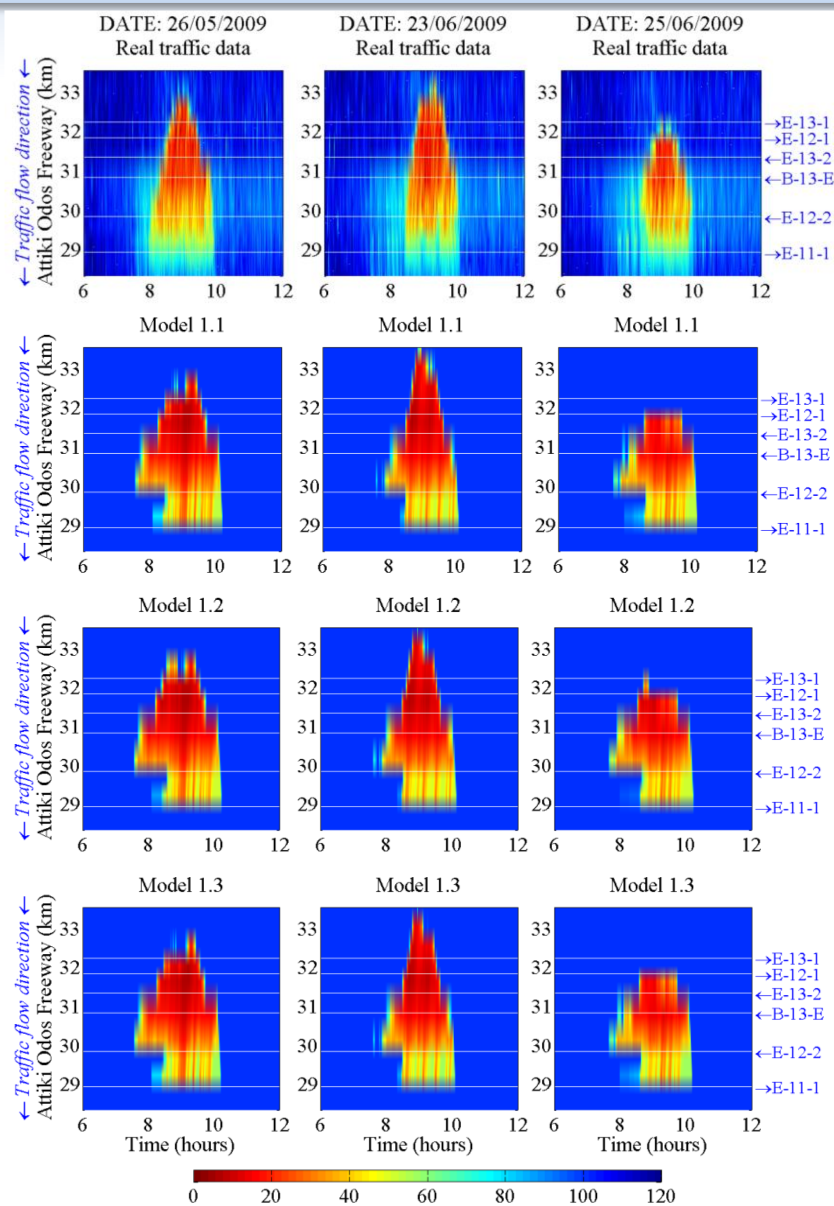


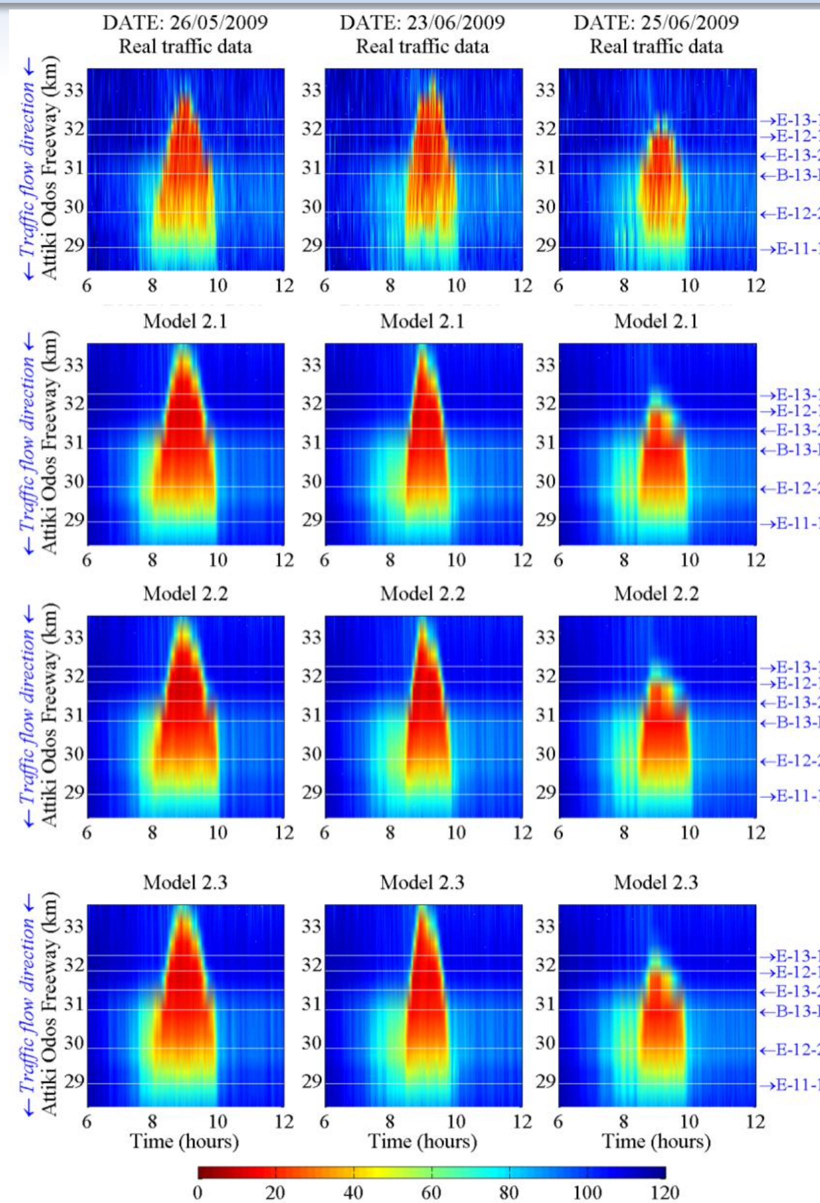
Calibration and validation results: Models' validation

- Model validation aims to test the accuracy and robustness of the produced models. To this end the models are applied using different traffic data sets.

	Model	Validation results (PI)				
		16/06/2009	26/05/2009	23/06/2009	25/06/2009	Average
CTM	Model 1.1	14.4	18.9	16.4	14.8	**16.1**
CTM	Model 2.1	14.7	19.7	16.8	16.3	**16.8**
CTM	Model 3.1	14.4	19.0	16.3	14.9	**16.2**
METANET	Model 2.1	10.1	12.1	12.4	8.4	**10.8**
METANET	Model 2.2	9.8	12.3	11.8	9.1	**10.8**
METANET	Model 2.3	9.9	12.6	12.4	8.3	**10.8**

Calibration and validation results:
Models' validation





Conclusions and remarks

- Two macroscopic traffic flow models were tested and compared regarding the representation of traffic congestion created due to a saturated freeway off-ramp.
- The models' parameter values were estimated using real traffic data and various optimization algorithms.
- The validation results showed that both models are able to reproduce traffic congestion due to an over-spilling off-ramp with sufficient accuracy.
- METANET model offers a more accurate representation of the prevailing traffic conditions.

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Calibration of Macroscopic Traffic Flow Models

Real-Time Traffic Control Measures : Case 1 – Route diversion control

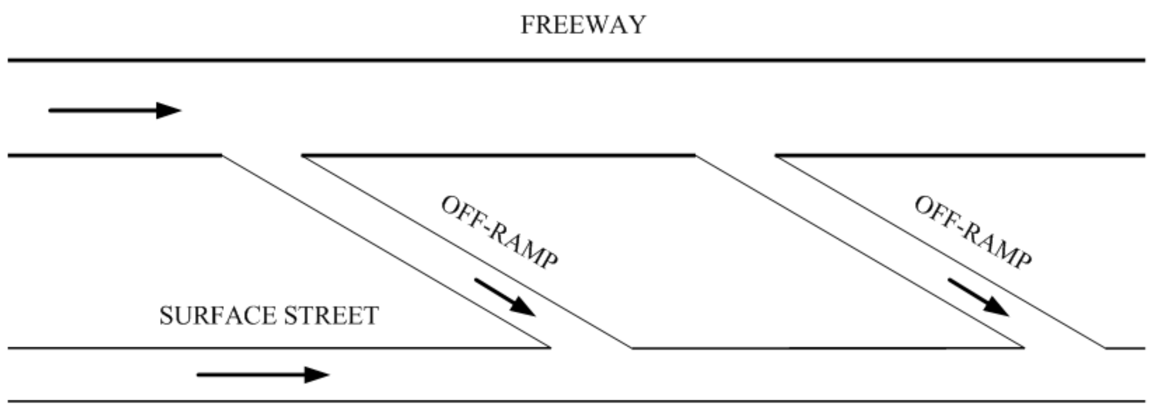
- Introduction
- Dynamic route diversion concept
- Test network and traffic demand scenarios
- Simulation investigations
- Conclusions and remarks

Introduction

- Freeway congestion due to saturated off-ramps is a particular type of congestion thus different freeway sites may call for different traffic control measures.
- Each situation should be viewed as a particular case and the corresponding network characteristics should be taken into account during the development of traffic control strategies.
- In the first examined case, freeway congestion is created due to the limited capacity of an off-ramp, which is not possible to increase.
- Various route diversion strategies are proposed that aim to reroute the drivers through alternative routes.

Dynamic route diversion concept: Problem description

Consider the following network:



Dynamic route diversion concept: Problem description

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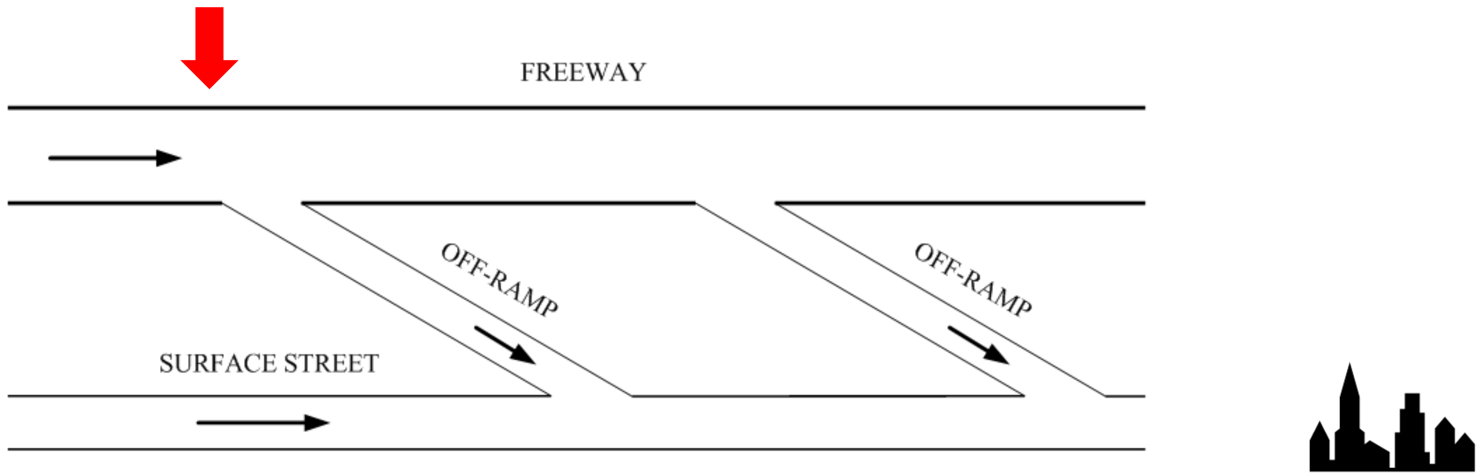

Dynamic route diversion concept: Problem description

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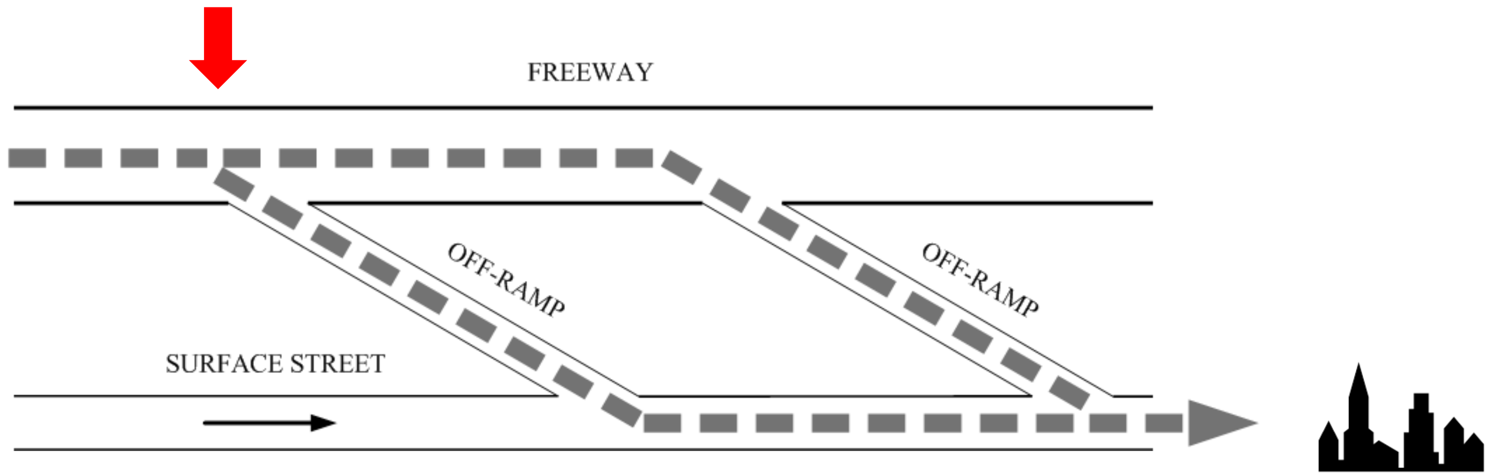
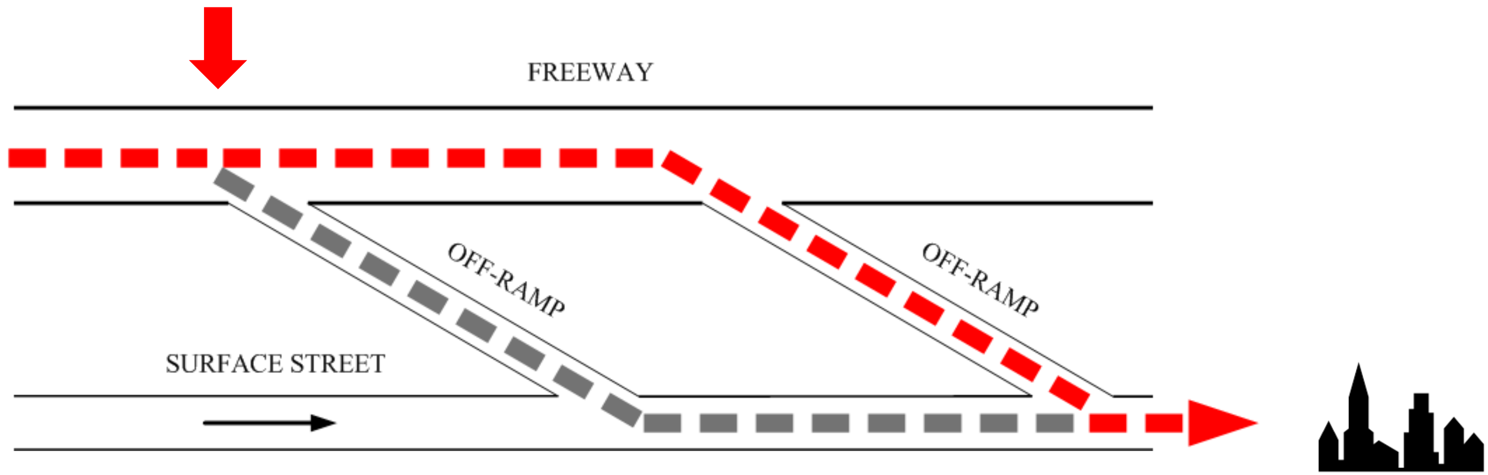


Dynamic route diversion concept:
Problem description

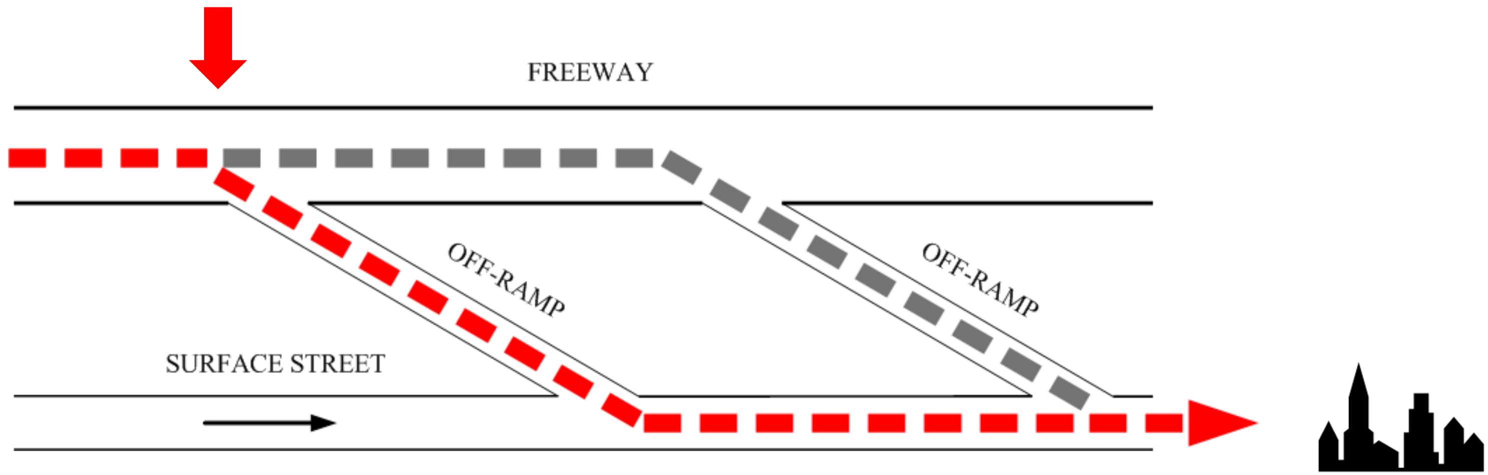
Consider the following network:



- Primary route ➡ distance-shorter route.

Dynamic route diversion concept: Problem description

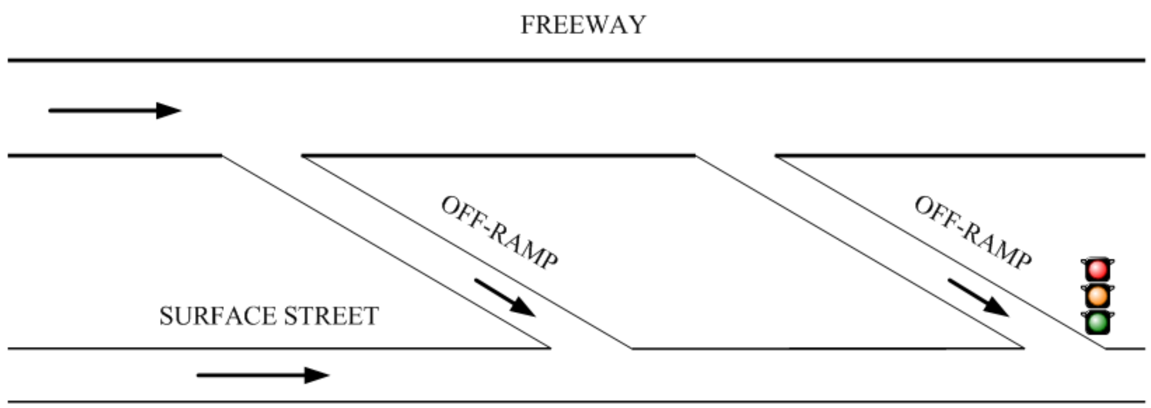
Consider the following network:



- Primary route ➔ distance-shorter route.

Dynamic route diversion concept:
Problem description

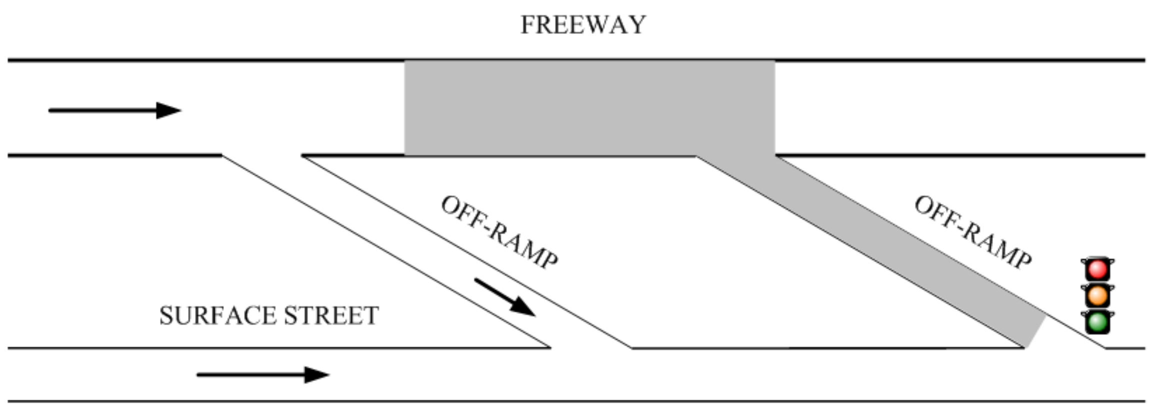
Consider the following network:



- Primary route ➡ distance-shorter route.
- Primary route off-ramp ➡ limited capacity.

Dynamic route diversion concept:
Problem description

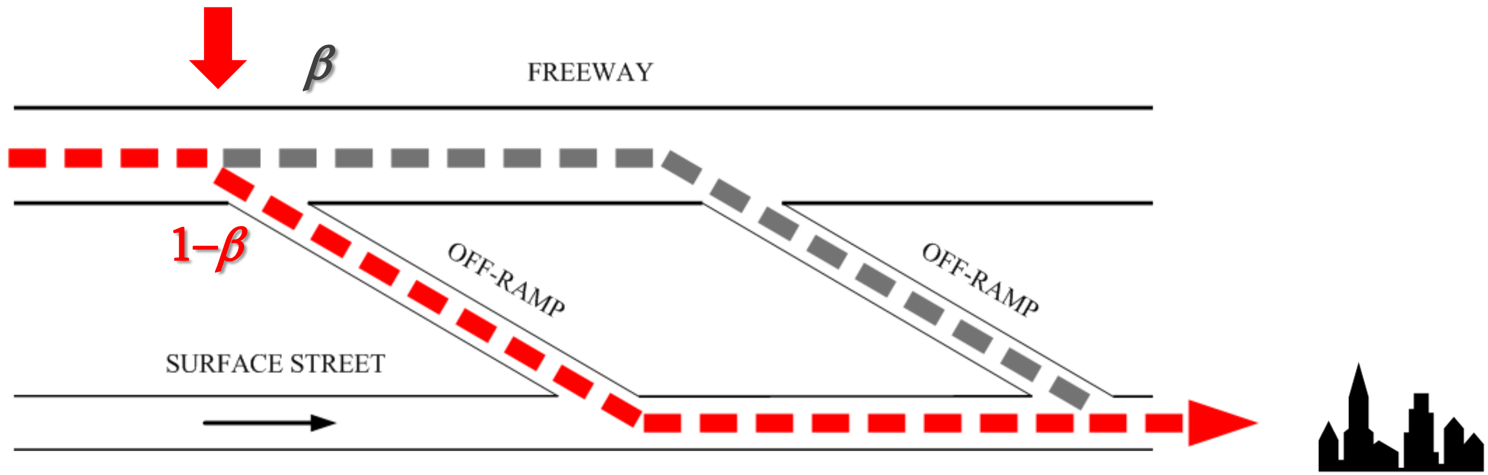
Consider the following network:



- Primary route ➡ distance-shorter route.
- Primary route off-ramp ➡ limited capacity.

Dynamic route diversion concept: Problem description

Consider the following network:



- Primary route → distance-shorter route.
- Primary route off-ramp → limited capacity.
- Concept: divert a portion of traffic, $1-\beta$, through the alternative route.

Dynamic route diversion concept: Problem description

The route diversion concept can be applied through:

Variable Message Signs (VMS)

Vehicle to Infrastructure Communication

However, drivers are free to ignore messages

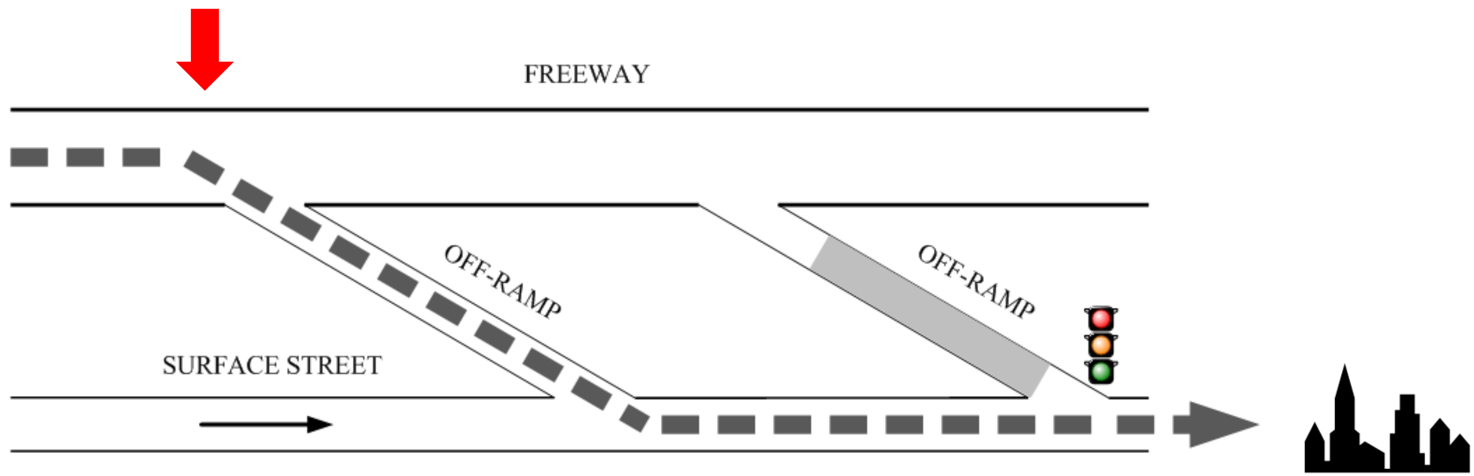
…that they perceive incompatible with their own criteria!

Dynamic route diversion concept: Problem description

- The objective of the route diversion system should not only be the system optimal conditions, but must mainly target user-optimal conditions.

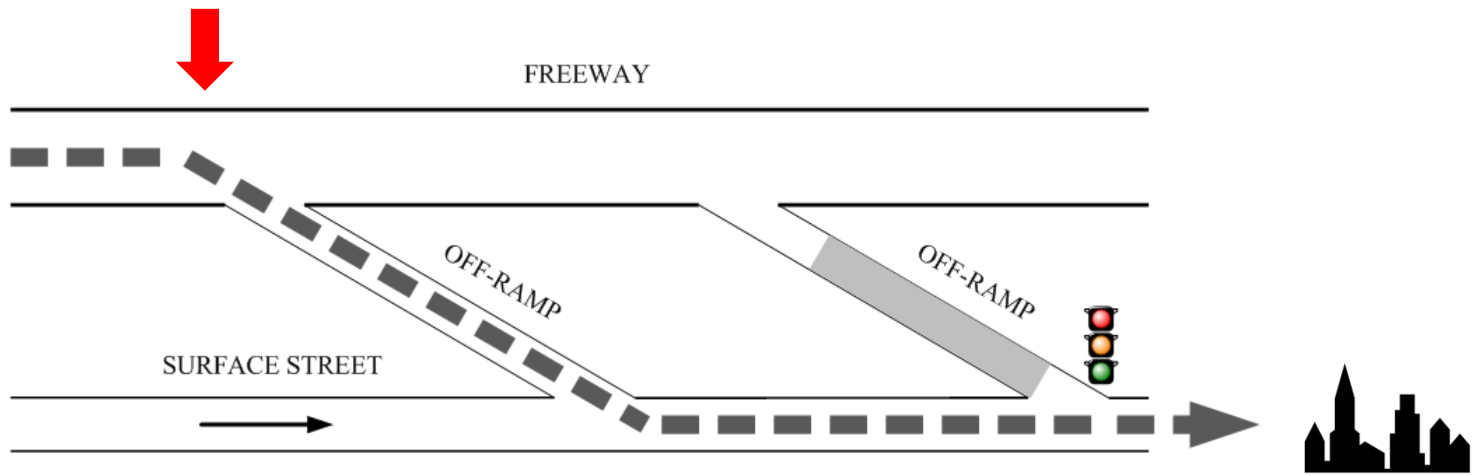
- Depending on the network topology and traffic conditions, three different cases arise:

Dynamic route diversion concept: Problem description



- Case 1: The user-optimal conditions may be achieved before the off-ramp queue spill-over.
- Case 2: The user-optimal conditions are achieved only after the off-ramp queue spill-over and creation of mainstream congestion.
- Case 3: The user-optimal conditions may not be achievable.

Dynamic route diversion concept:
Problem description



- Case 1: The user-optimal conditions may be achieved before the off-ramp queue spill-over.
  - Dynamic route diversion based on reactive travel time estimation.
  - Dynamic route diversion based on off-ramp queue length estimation.
- Case 2: The user-optimal conditions are achieved only after the off-ramp queue spill-over and creation of mainstream congestion.
- Case 3: The user-optimal conditions may not be achievable.

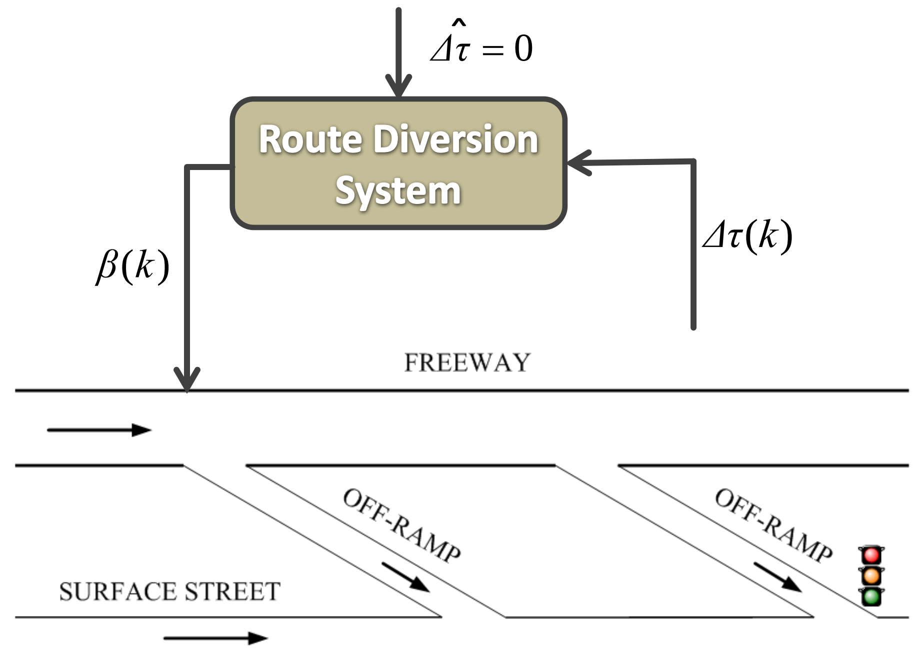
Dynamic route diversion concept:

Case 1: User-optimal conditions may be achieved before the off-ramp queue spill-over

A. Dynamic route diversion based on reactive travel time estimation

$\tau(k)$: reactive (estimated) travel time

$$\Delta\tau(k) = \tau^{s}(k) - \tau^{p}(k)$$



PI feedback strategy:

$$\beta(k) = \beta(k-1) + K_p\left[\Delta\tau(k) - \Delta\tau(k-1)\right] + K_i\Delta\tau(k)$$

$$\beta(k) \in [0,1]$$

Dynamic route diversion concept:

Case 1: User-optimal conditions may be achieved before the off-ramp queue spill-over

B. Dynamic route diversion based on off-ramp queue length estimation

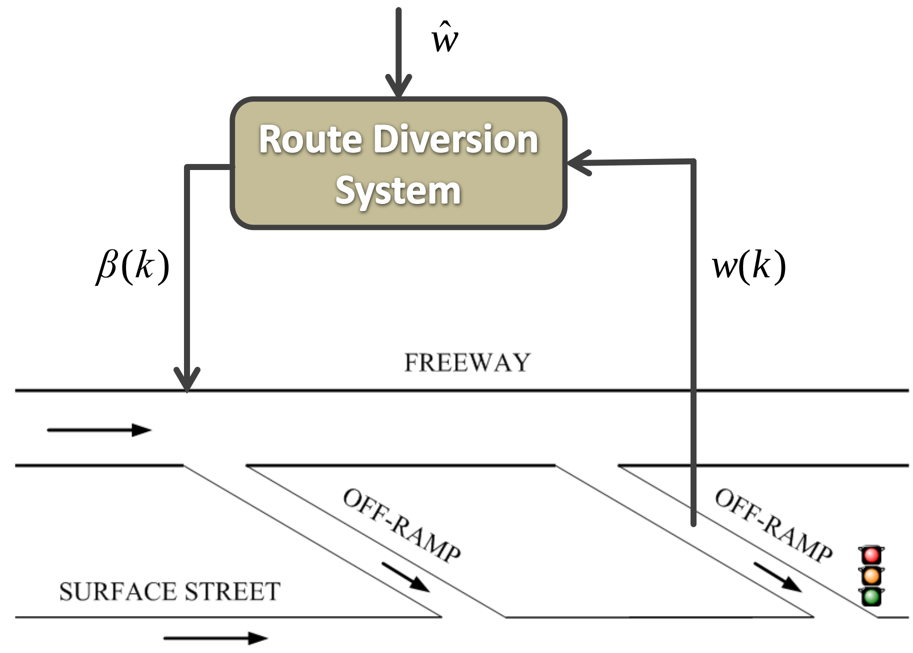
$w(k)$: off-ramp queue estimation

$\hat{w}$: desired queue level

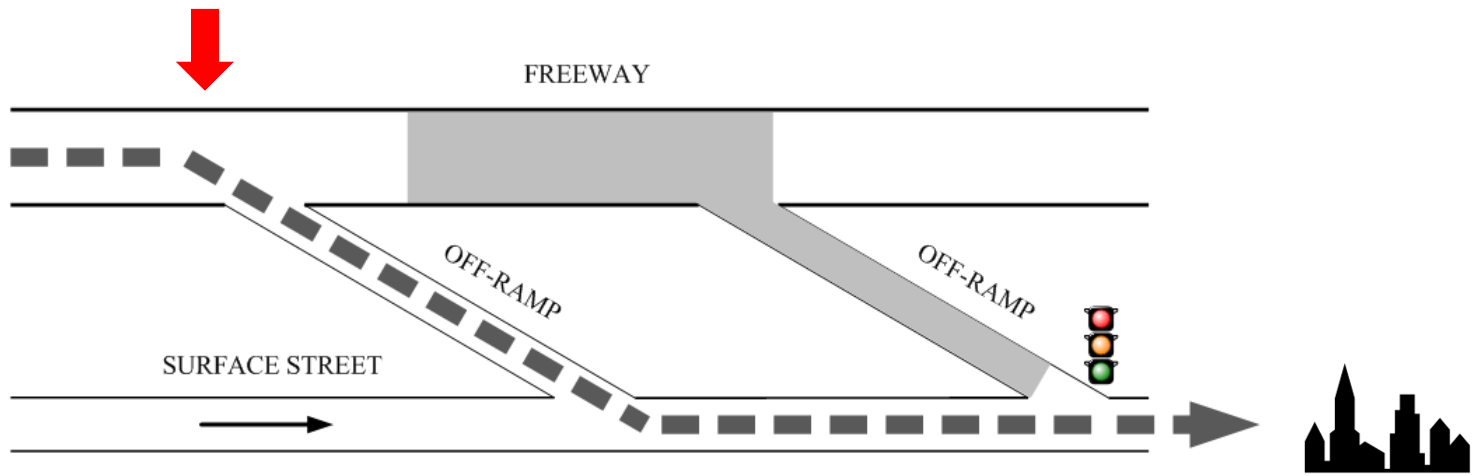
PI feedback strategy:

$$\beta(k) = \beta(k-1) + K_p\left[w(k-1) - w(k)\right] + K_i\left[\hat{w} - w(k)\right]$$

$$\beta(k) \in [0,1]$$

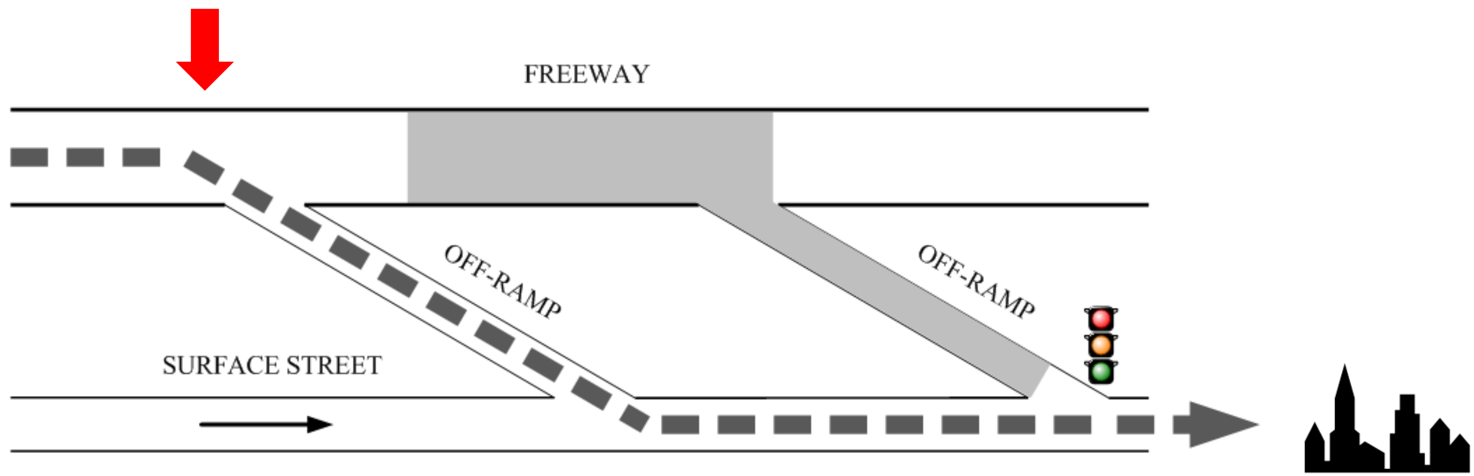


Dynamic route diversion concept: Problem description



- Case 1: The user-optimal conditions may be achieved before the off-ramp queue spill-over.
- Case 2: The user-optimal conditions are achieved only after the off-ramp queue spill-over and creation of mainstream congestion.
- Case 3: The user-optimal conditions may not be achievable.

Dynamic route diversion concept: Problem description



- Case 1: The user-optimal conditions may be achieved before the off-ramp queue spill-over.
- Case 2: The user-optimal conditions are achieved only after the off-ramp queue spill-over and creation of mainstream congestion.
  - Dynamic route diversion based on off-ramp queue length estimation.
  - Dynamic route diversion through temporary off-ramp closures.
- Case 3: The user-optimal conditions may not be achievable.

Dynamic route diversion concept:

Case 2: User-optimal conditions may be achieved only after the off-ramp queue spill-over

A. Dynamic route diversion based on off-ramp queue length estimation

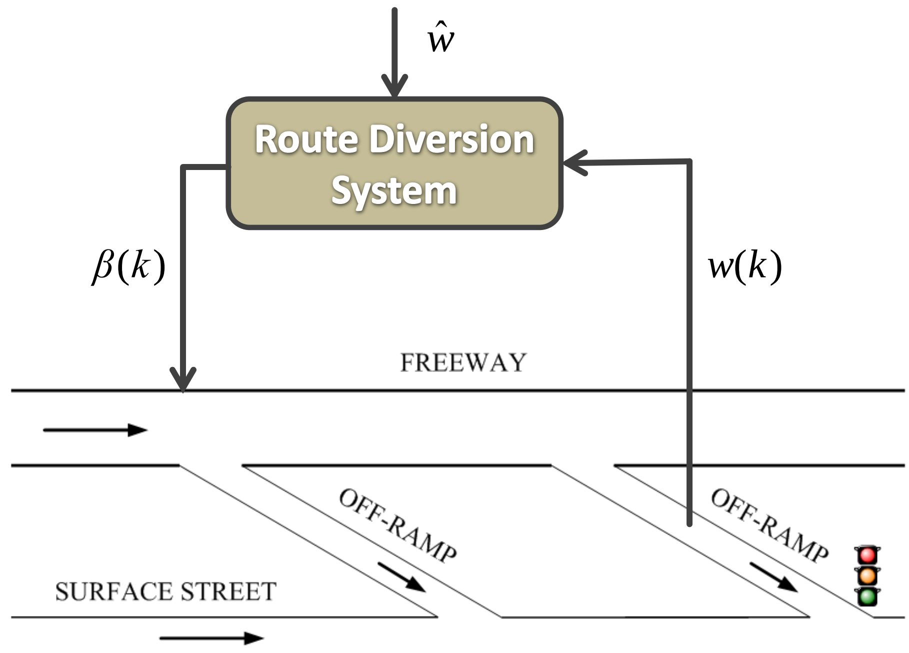
$w(k)$: off-ramp queue estimation

$\hat{w}$: desired queue level

PI feedback strategy:

$$\beta(k) = \beta(k-1) + K_p\left[w(k-1) - w(k)\right] + K_i\left[\hat{w} - w(k)\right]$$

$$\beta(k) \in [0,1]$$



Dynamic route diversion concept:

Case 2: User-optimal conditions may be achieved only after the off-ramp queue spill-over

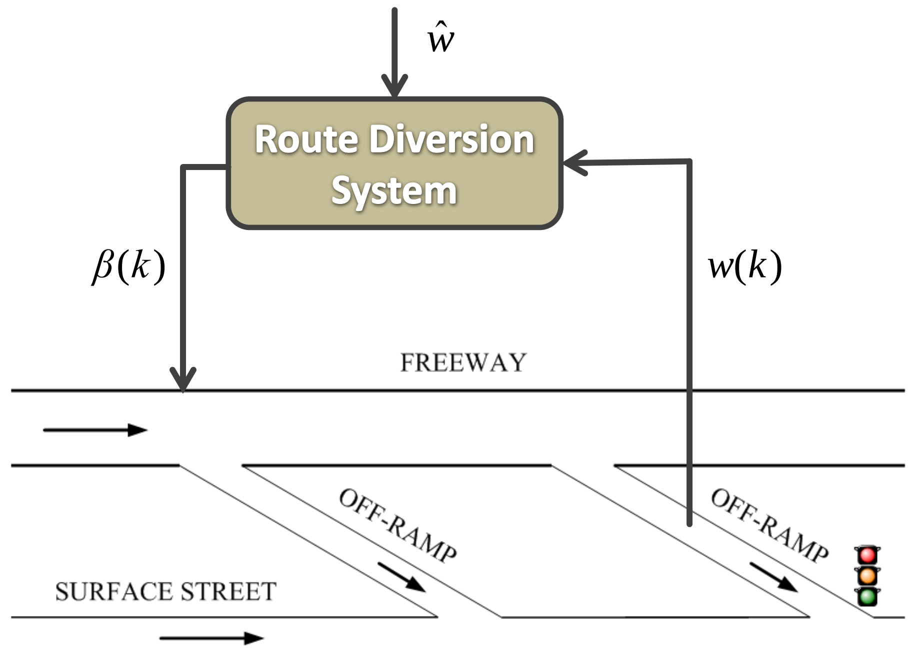
B. Dynamic route diversion through temporary off-ramp closures

$w(k)$: off-ramp queue estimation

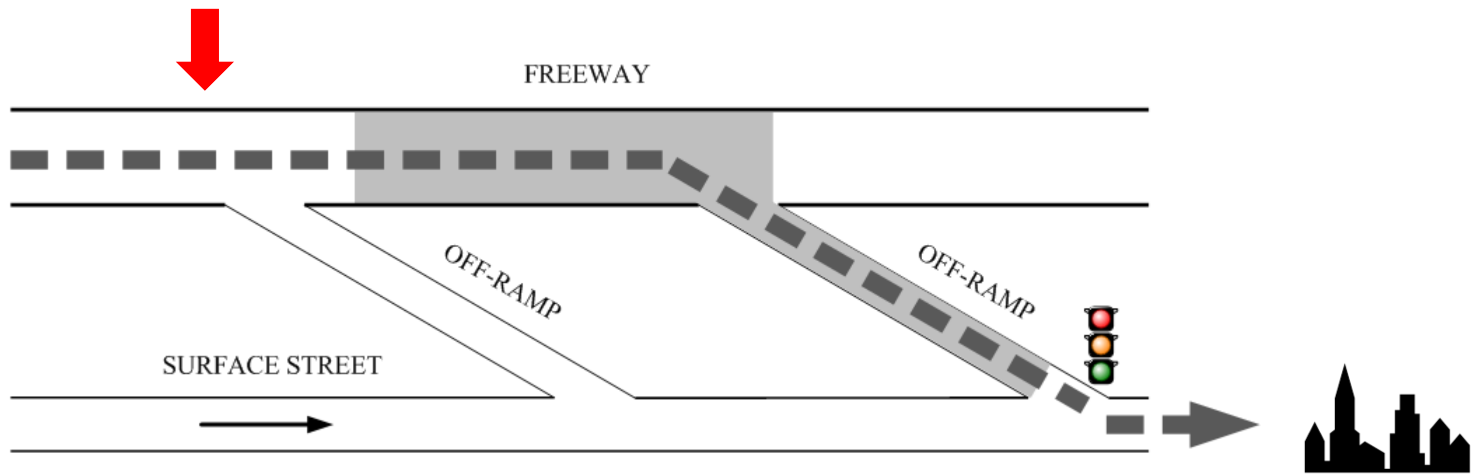
$\hat{w}$: desired queue level

Bang-Bang feedback strategy:

$$\beta(k) = \begin{cases} 1 & if \quad w(k) < \hat{w} \\ 0 & otherwise \end{cases}$$



Dynamic route diversion concept: Problem description



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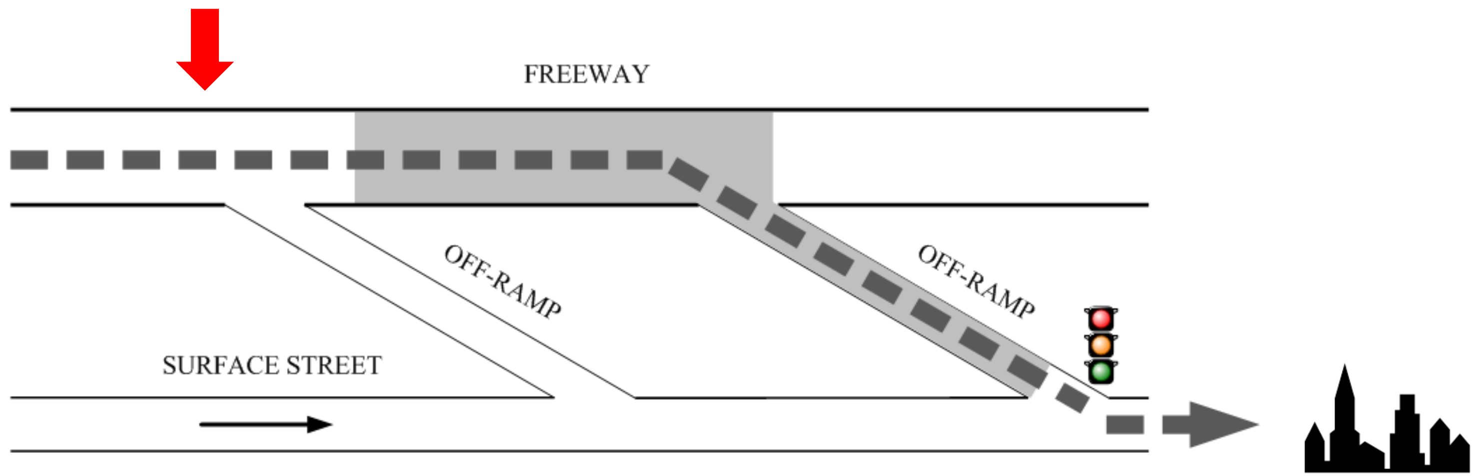
- Case 3: The user-optimal conditions may not be achievable.

Dynamic route diversion concept: Problem description



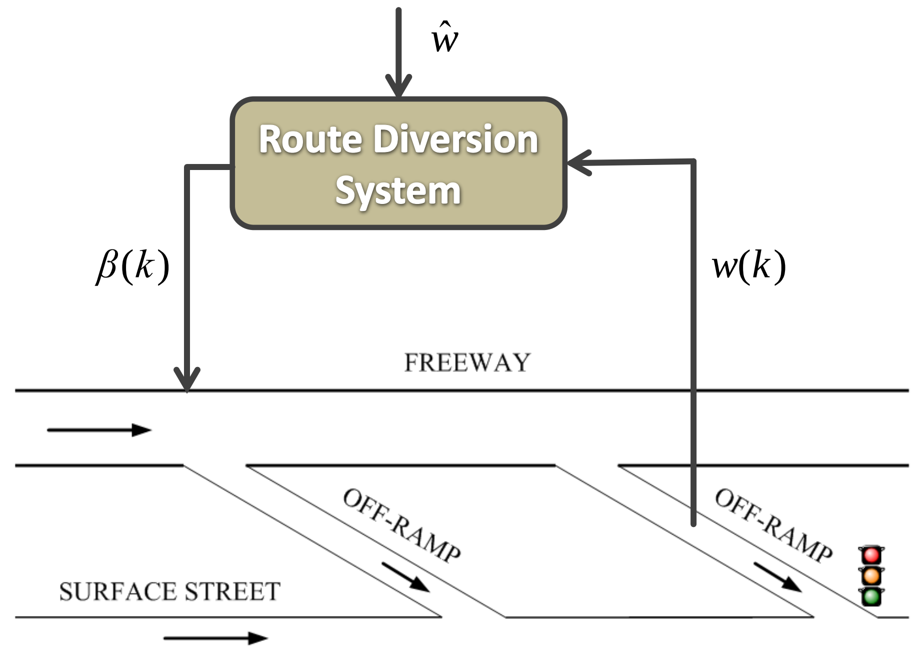
- Case 1: The user-optimal conditions may be achieved before the off-ramp queue spill-over.
- Case 2: The user-optimal conditions are achieved only after the off-ramp queue spill-over and creation of mainstream congestion.
- Case 3: The user-optimal conditions may not be achievable.
  - Dynamic route diversion through temporary off-ramp closures.

Dynamic route diversion concept:
Case 3: User-optimal conditions may not be achieved

A. Dynamic route diversion through temporary off-ramp closures

$w(k)$: off-ramp queue estimation

$\hat{w}$: desired queue level

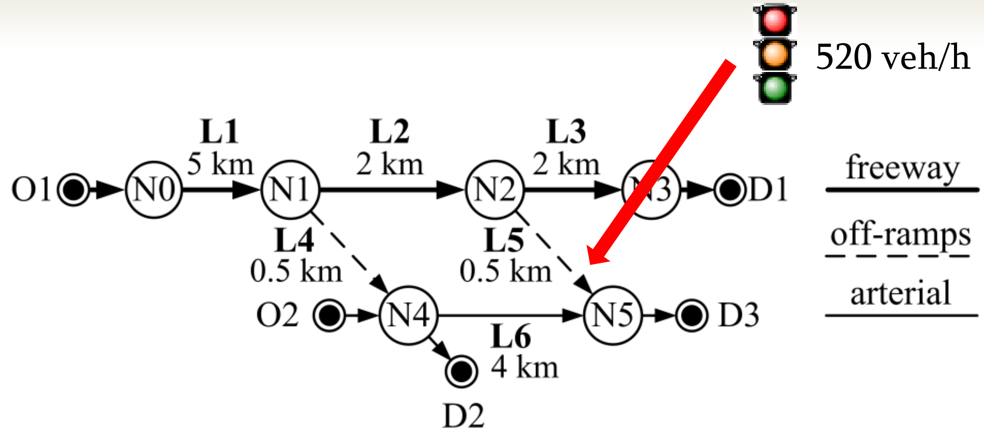


Bang-Bang feedback strategy:

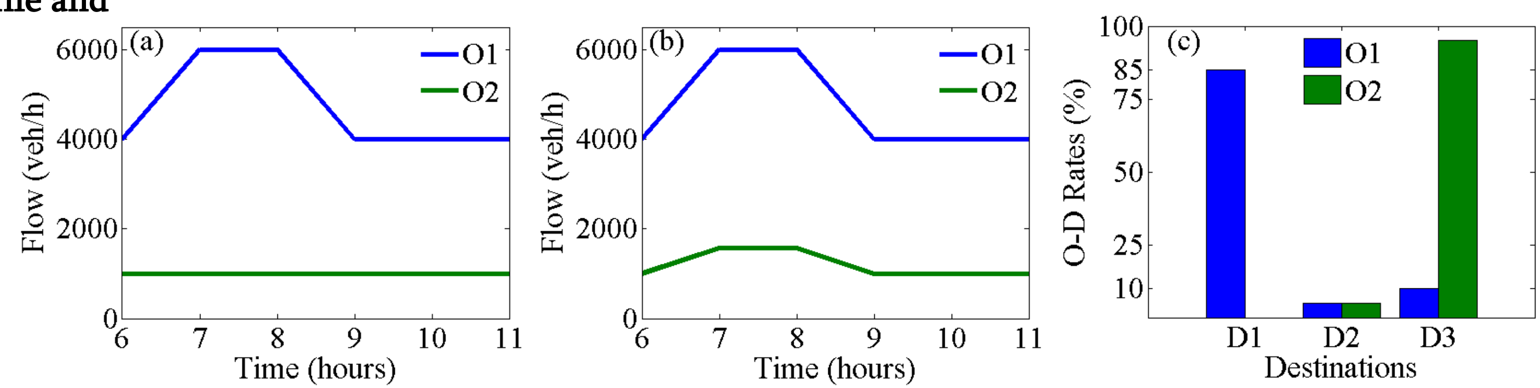
$$\beta(k) = \begin{cases} 1 & if \quad w(k) < \hat{w} \\ 0 & otherwise \end{cases}$$

Simulation set-up

Test network:
METANET Simulator



Demand profile and O-D rates:



Performance criteria:

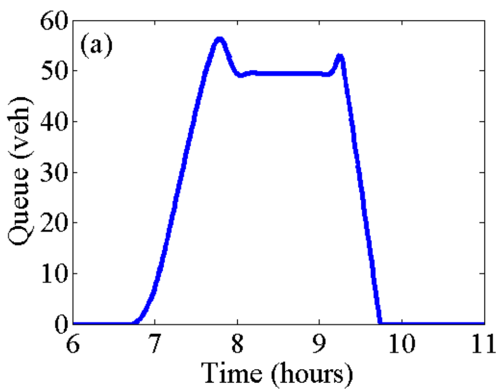
Total Time Spent (TTS) in veh ·h

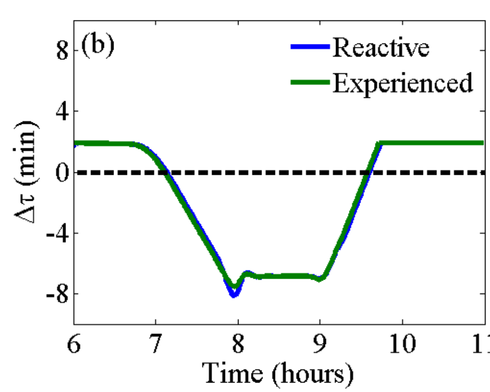
Total Disbenefit (TD) in veh ·h

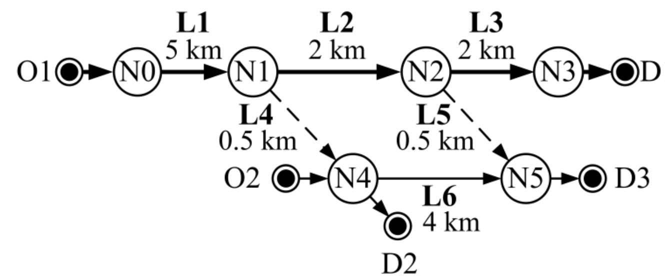
Simulation Investigations

Case 1: User-optimal conditions may be achieved before the off-ramp queue spill-over

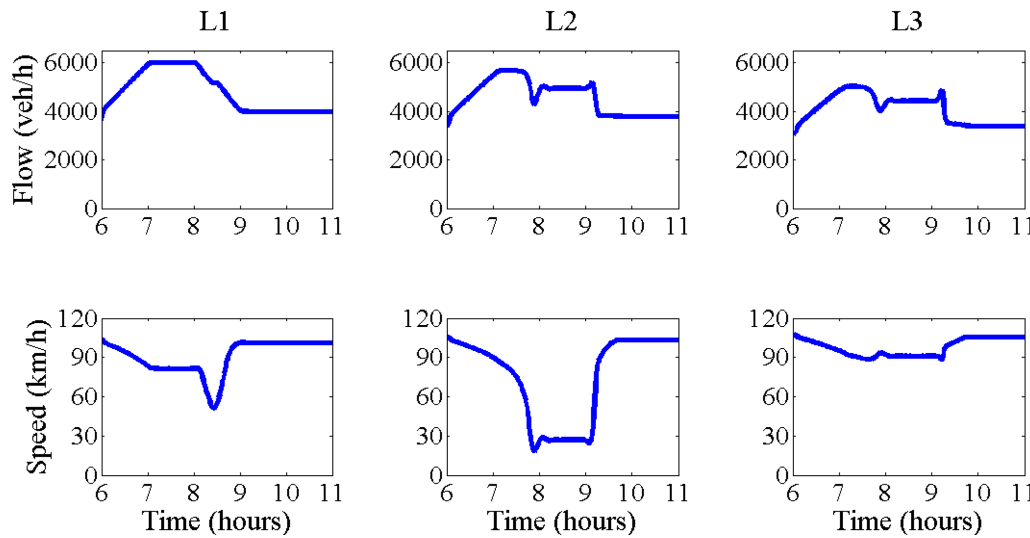
A. No route diversion







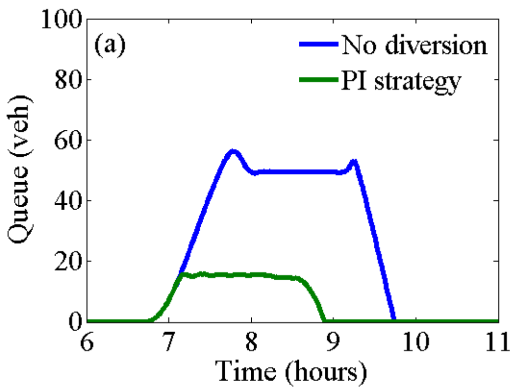
Route Guidance Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3228*	*110*

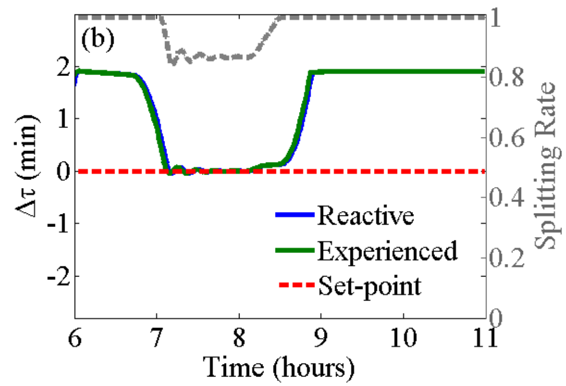


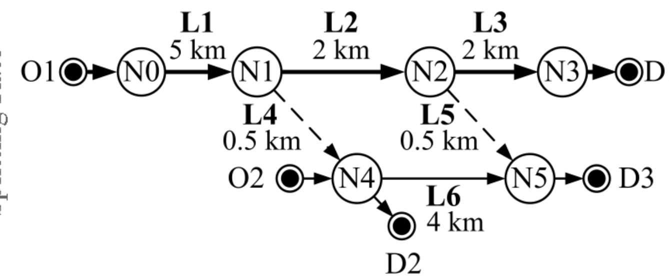
Simulation Investigations

Case 1: User-optimal conditions may be achieved before the off-ramp queue spill-over

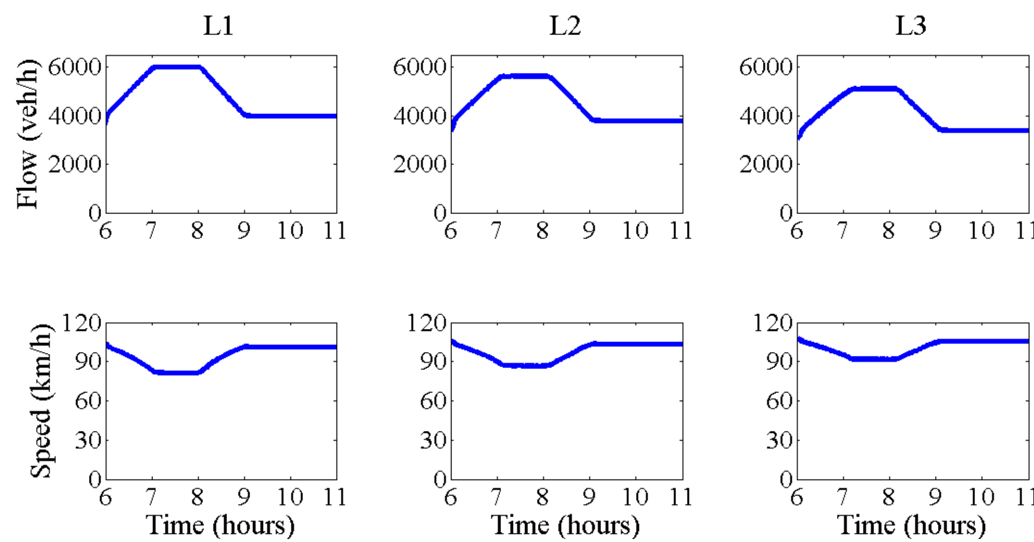
B. Dynamic route diversion based on reactive travel time estimation







Route Diversion Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3228*	**110**
B. Route diversion based on travel times	***2473 (-23%)***	***0.1 (-100%)***



PI-strategy parameters:

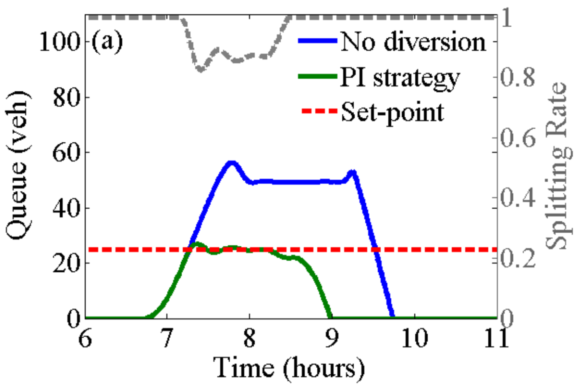
$K_p = 18,\ K_i = 6,$

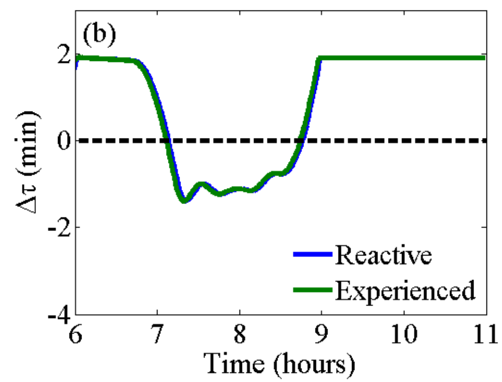
$\hat{\Delta}\tau = 0$ min, $T_c = 2$ min

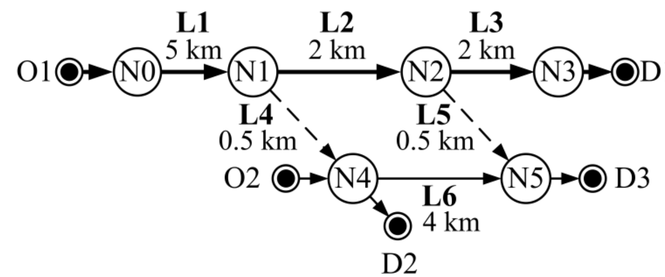
Simulation Investigations

Case 1: User-optimal conditions may be achieved before the off-ramp queue spill-over

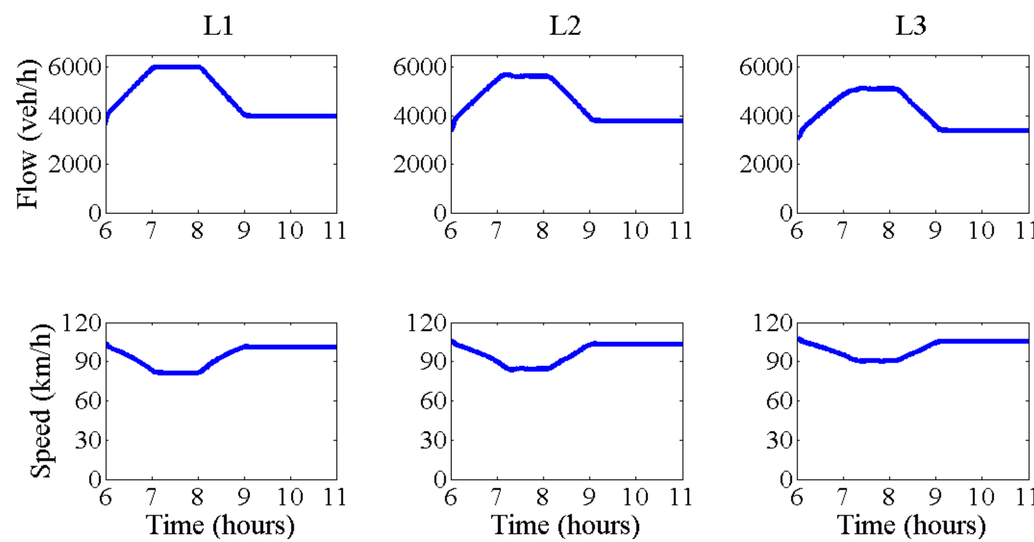
C. Dynamic route diversion based on off-ramp queue length estimation







Route Diversion Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3228*	**110**
B. Route diversion based on travel times	*2473 (-23%)*	*0.1 (-100%)*
C. Route diversion based on queue length	***2500 (-23%)***	***13.7 (-88%)***



PI-strategy parameters:

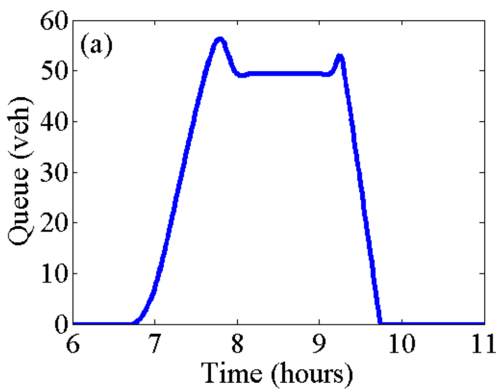
$K_p = 0.02,\ K_i = 0.005,$

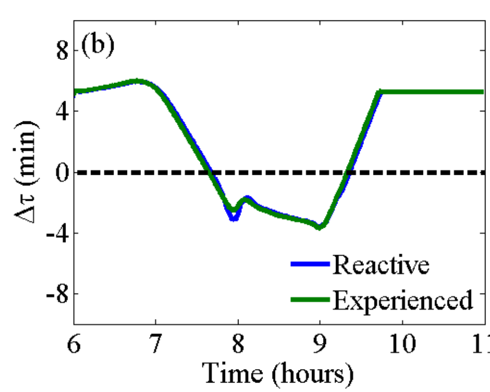
$\hat{w} = 25$ veh, $T_c = 2$ min

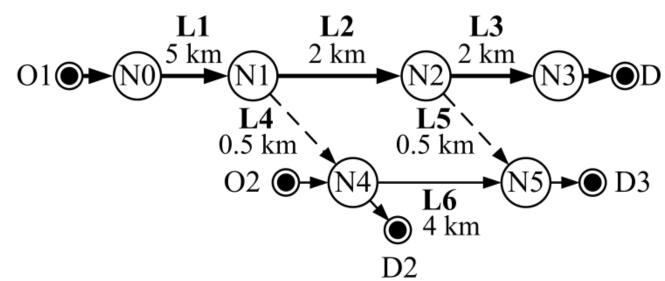
Simulation Investigations

Case 2: User-optimal conditions may be achieved only after the off-ramp queue spill-over

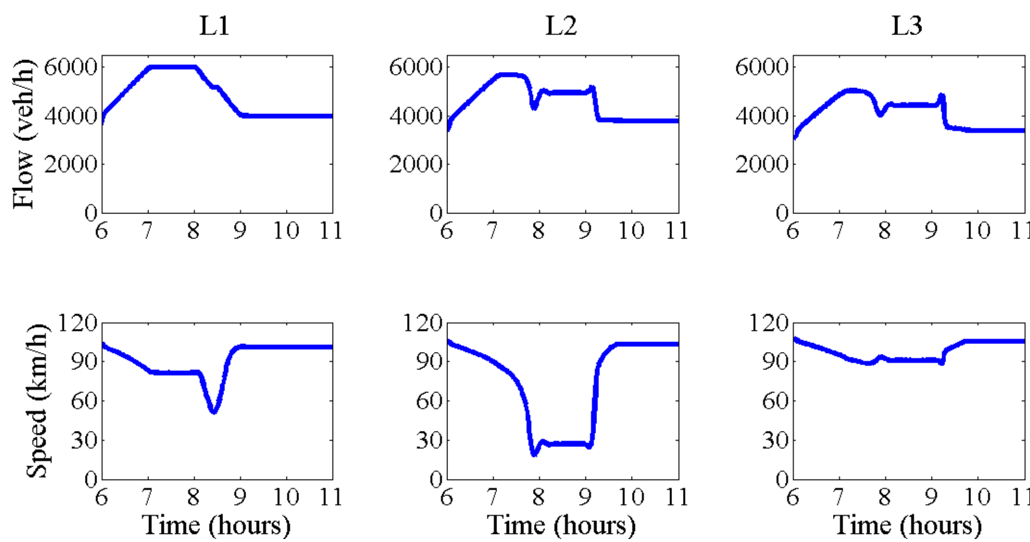
A. No route diversion







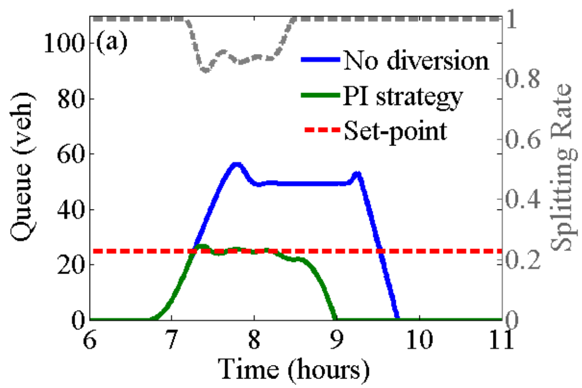
Route Diversion Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3637*	*34.3*

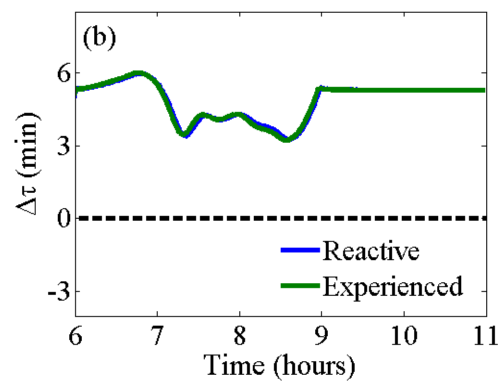


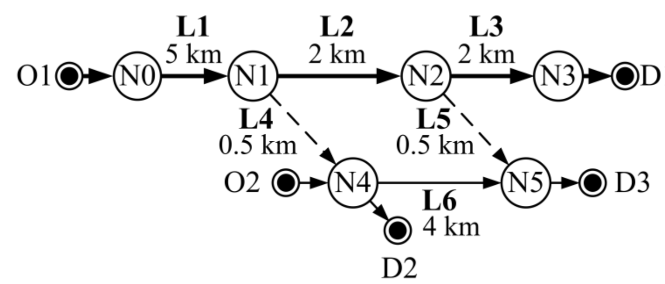
Simulation Investigations

Case 2: User-optimal conditions may be achieved only after the off-ramp queue spill-over

B. Dynamic route diversion based on off-ramp queue length estimation





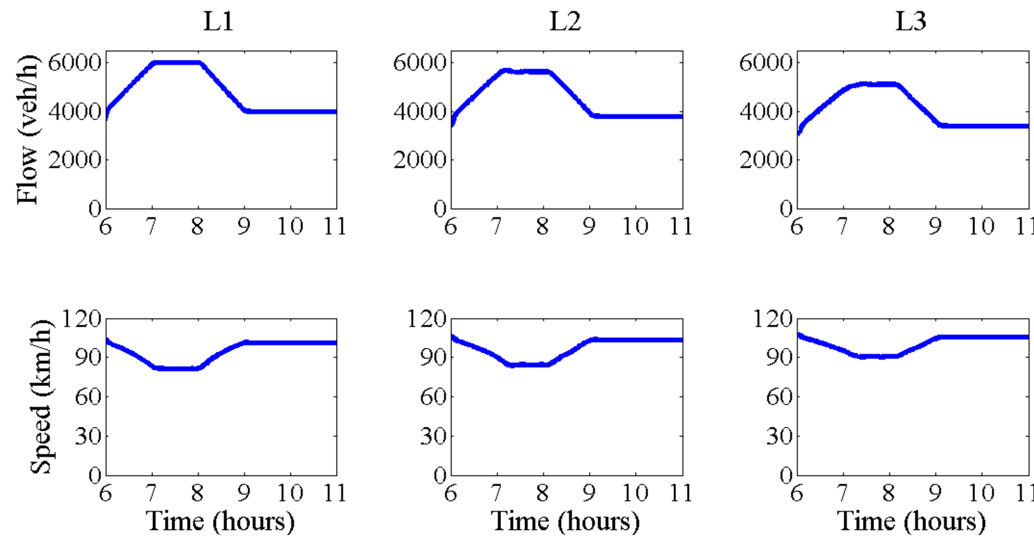


Route Diversion Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3637*	**34.3**
B. Route diversion based on queue length	***2927 (-20%)***	***5.9 (-83%)***

PI-strategy parameters:

$K_p = 0.02,\ K_i = 0.005,$

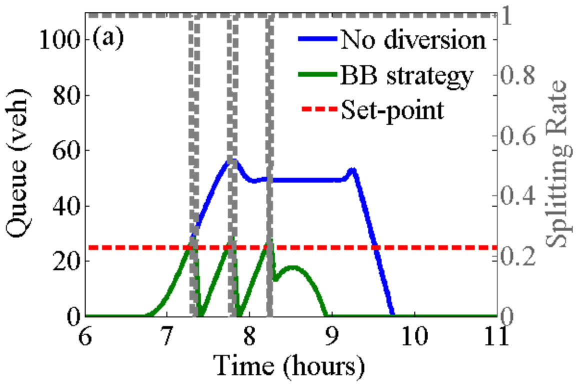
$\hat{w} = 25$ veh, $T_c = 2$ min

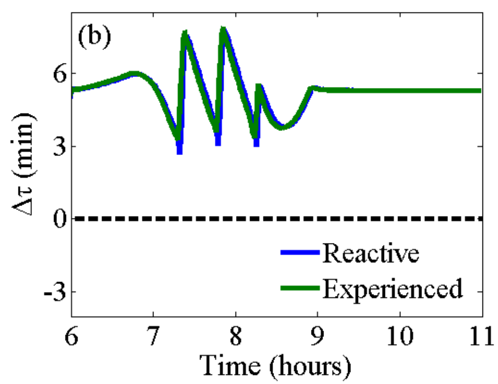


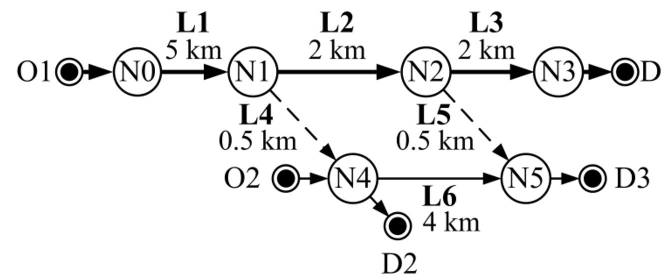
Simulation Investigations

Case 2: User-optimal conditions may be achieved only after the off-ramp queue spill-over

C. Dynamic route diversion through temporary off-ramp closures



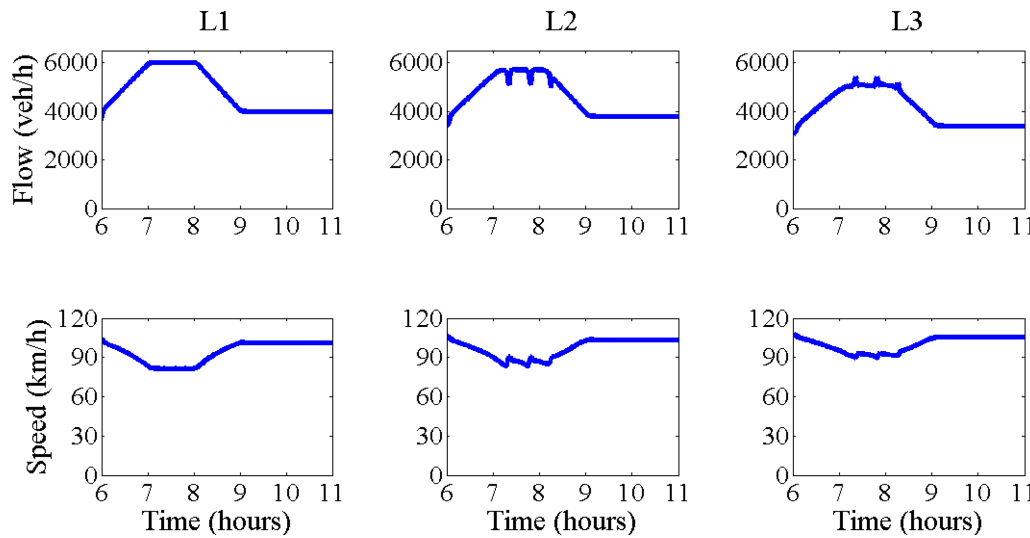




Route Diversion Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3637*	*34.3*
B. Route diversion based on queue length	*2927 (-20%)*	*5.9 (-83%)*
C. Route diversion through temporary off-ramp closures	***2916 (-20%)***	***8.3 (-76%)***

Bang-Bang strategy:

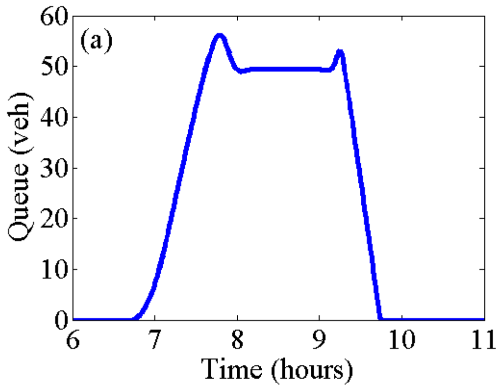
$\hat{w} = 25$ veh, $T_c = 2$ min

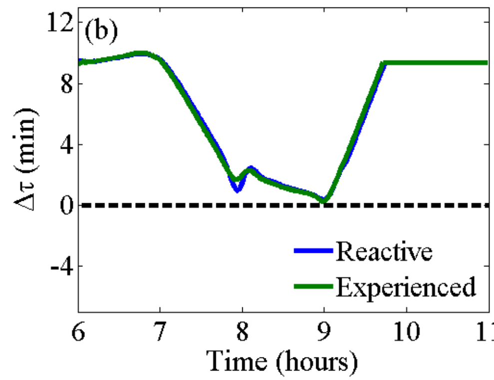


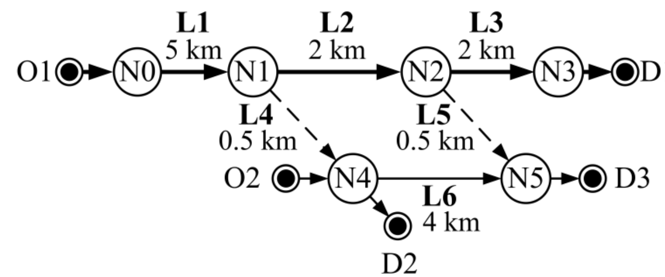
Simulation Investigations

Case 3: User-optimal conditions may not be achieved

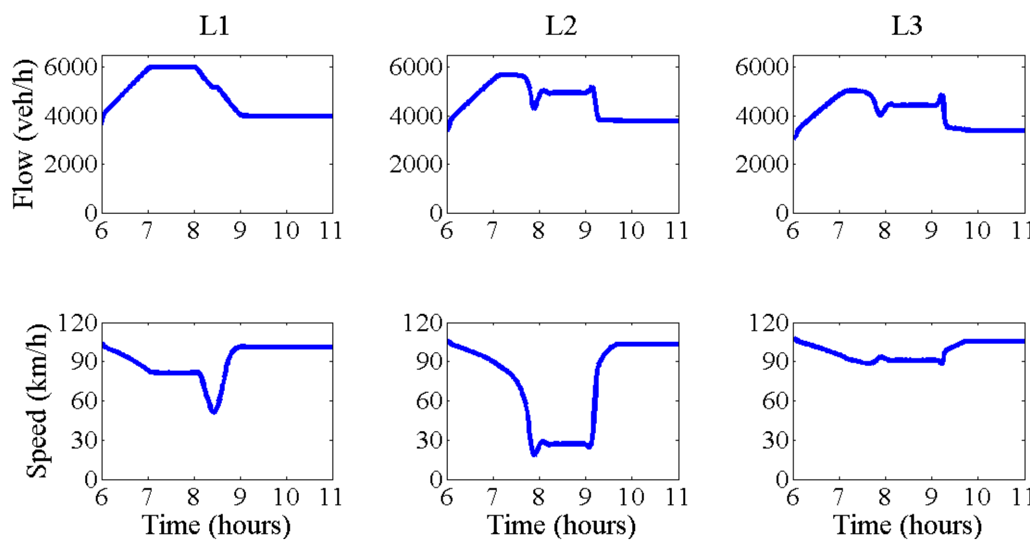
A. No route diversion







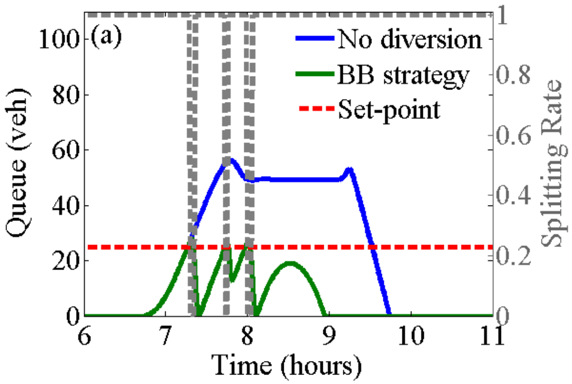
Route Diversion Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3979*	*0*

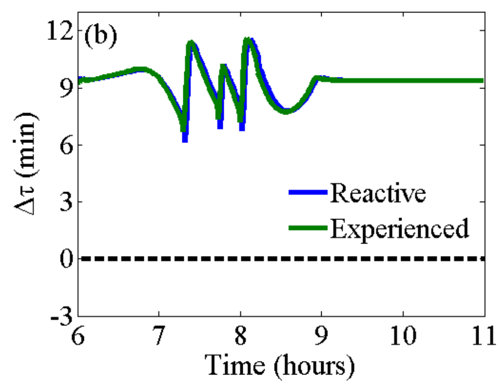


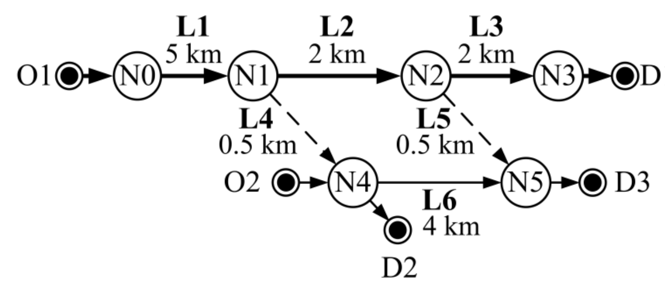
Simulation Investigations

Case 3: User-optimal conditions may not be achieved

B. Dynamic route diversion through temporary off-ramp closures



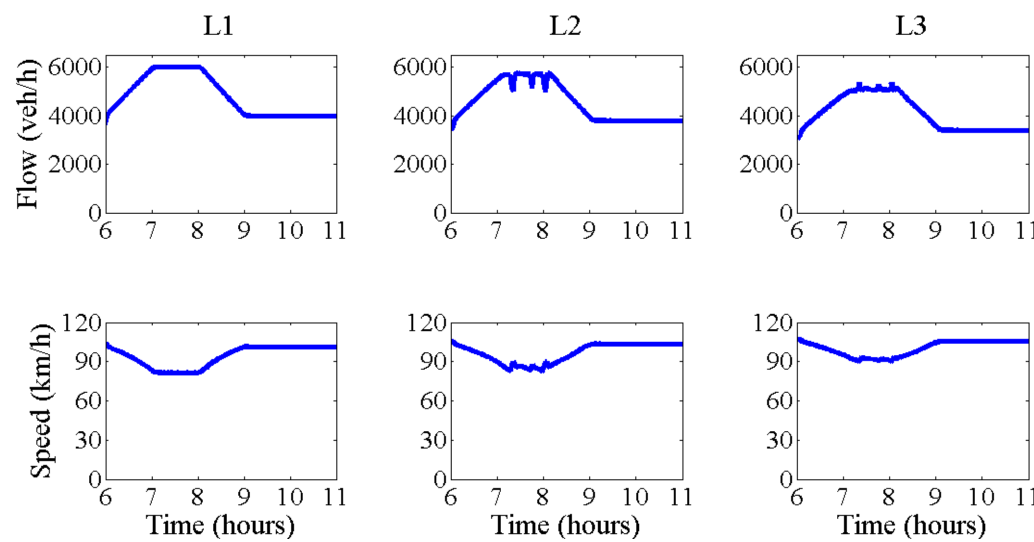




Route Diversion Policy	TTS (veh·h)	TD (veh·h)
A. No route diversion	*3979*	*0*
B. Route diversion based on temporary off-ramp closures	***3263 (-18%)***	***14.5***

Bang-Bang strategy:

$\hat{w} = 25$ veh, $T_c = 2$ min



Conclusions and remarks

- Various route diversion policies are proposed that aim to prevent recurrent freeway congestion which is triggered by a saturated off-ramp.
- The proposed policies employ simple but efficient feedback laws and attempt to reroute the drivers through alternative routes.
- The simulation results showed that, in all investigated cases, the proposed policies succeed in maintaining the off-ramp queue length within the off-ramp bounds.

Outline

Introduction

Calibration of Macroscopic Traffic Flow Models

Real-Time Traffic Control Measures : Case 1 – Route diversion control

Real-Time Traffic Control Measures : Case 2 – Merging traffic control

Conclusions and Future Work

Outline

Introduction

Calibration of Macroscopic Traffic Flow Models

Real-Time Traffic Control Measures : Case 1 – Route diversion control

Real-Time Traffic Control Measures : Case 2 – Merging traffic control

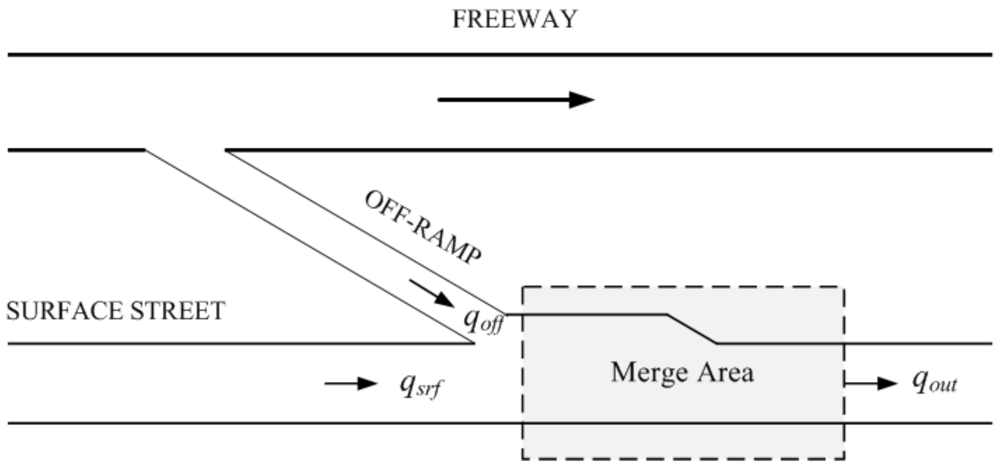
- Introduction
- Real-time merging traffic control concept
- Network description and traffic demand pattern
- Simulation investigations
- Conclusions and remarks

Introduction

- In the second examined case, recurrent freeway congestion is created due to congestion on the surface street network.
- The proposed control algorithm aims to maximize the surface street merge area outflow and prevent the off-ramp queue spill over.
- A real traffic network in Santiago, Chile, is utilized to demonstrate the application of the proposed control concept by use of microscopic simulation.

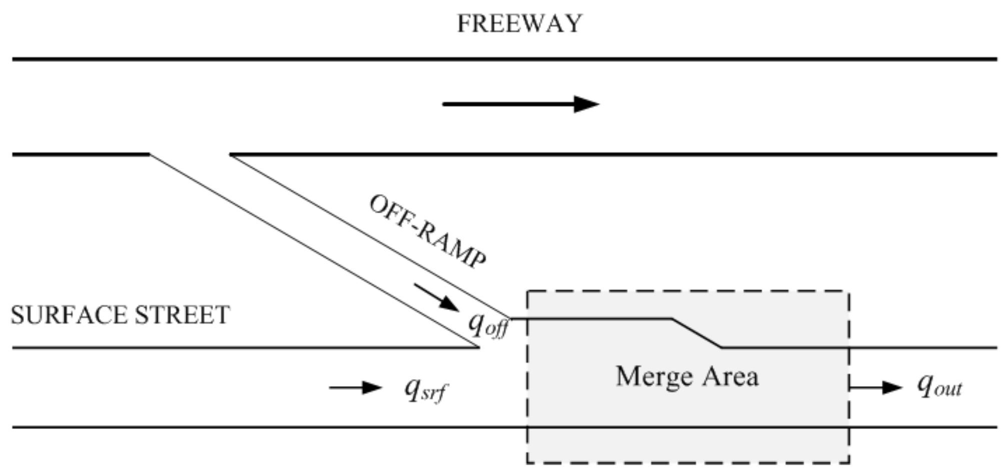
Real-time merging traffic control concept
Problem description

Consider the following network:



Real-time merging traffic control concept
Problem description

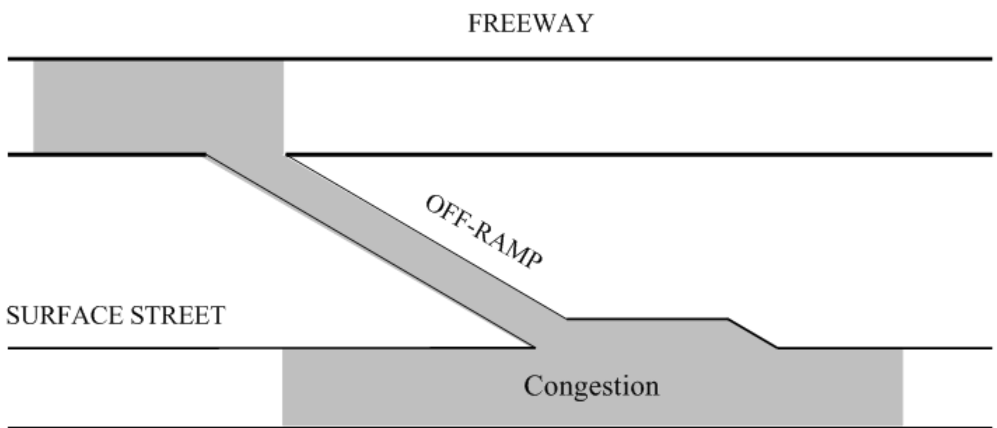
Consider the following network:



- The merge area is a potential bottleneck location, which may be activated during the peak hours.

Real-time merging traffic control concept
Problem description

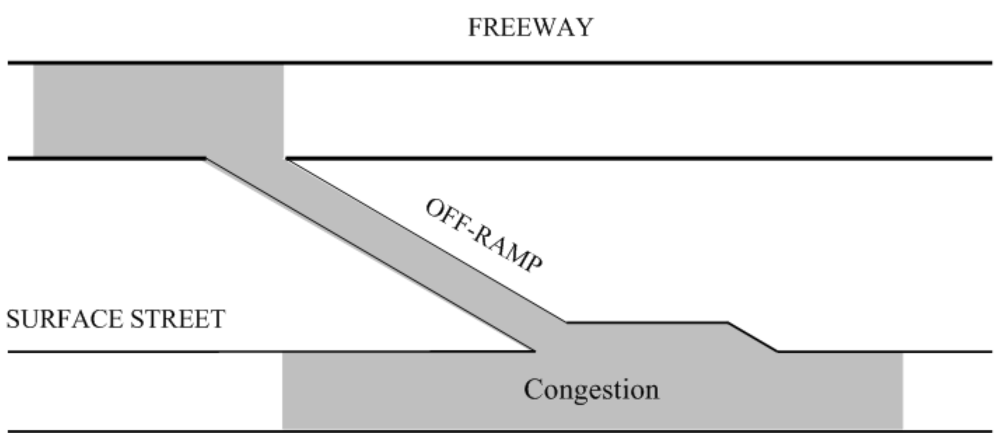
Consider the following network:



- The merge area is a potential bottleneck location, which may be activated during the peak hours.
- The congestion on the surface street network may spill back into the freeway through the saturated off-ramp.

Real-time merging traffic control concept
Problem description

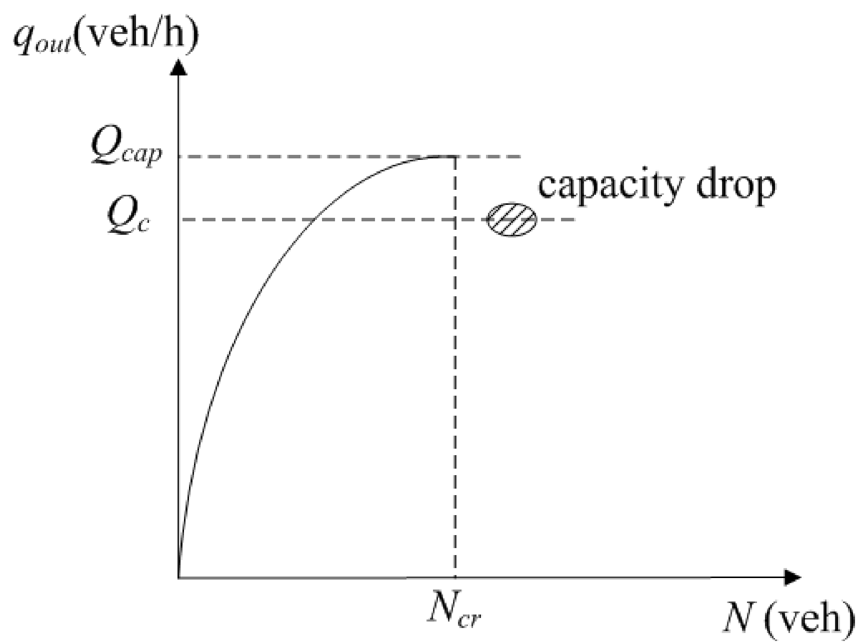
The merge area may be a bottleneck location due to a number of reasons:



- High arriving demand (including the surface street and the off-ramp demand).
- Infrastructure layout, e.g. lane drop.
- Strong weaving of traffic streams.
- Downstream urban traffic lights.
- Other capacity reducing events, such as incidents.

Real-time merging traffic control concept
Problem description

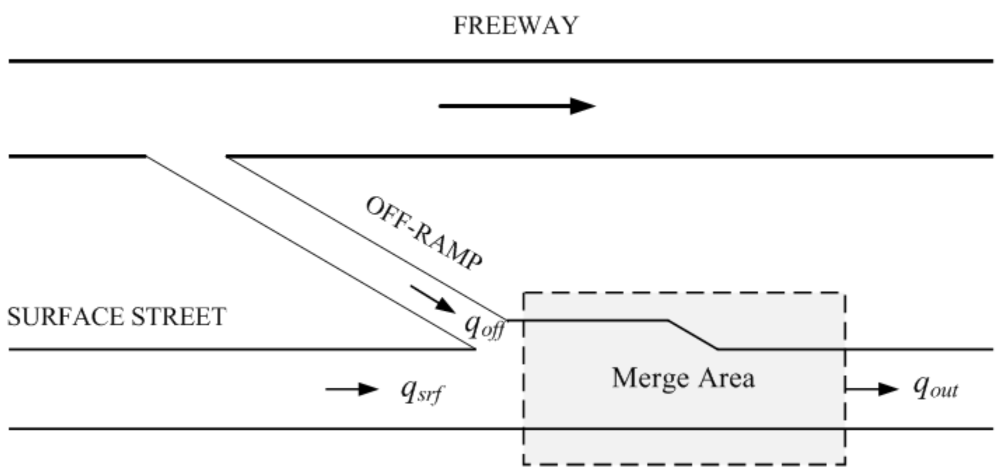
Fundamental diagram of a merge area:



Merging traffic control is proposed to restore capacity flow.

Real-time merging traffic control concept
Traffic control algorithm

Traffic control algorithm goals:



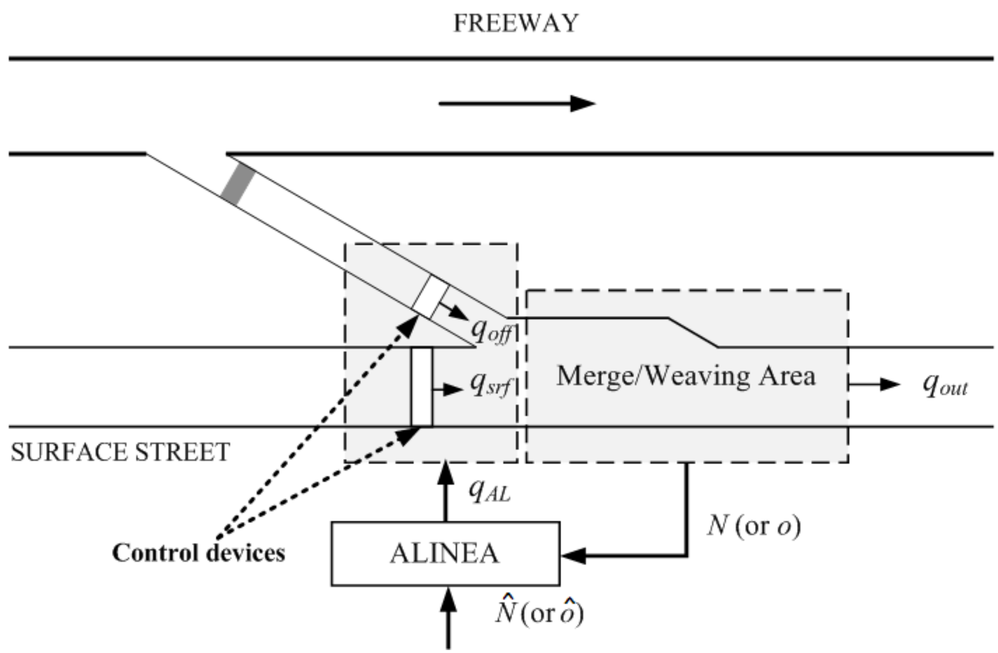
- Maximize the surface street merge area outflow.
- Prevent the off-ramp queue spill-over into the freeway mainstream.

Real-time merging traffic control concept
Traffic control algorithm

ALINEA feedback control strategy:

$$q_{AL}(k) = q_{AL}(k-1) - K_P[N(k-1) - N(k-2)] + K_I[\hat{N} - N(k-1)]$$

$$q_{AL}(k) \in [q_{\min},\ q_{\max}]$$

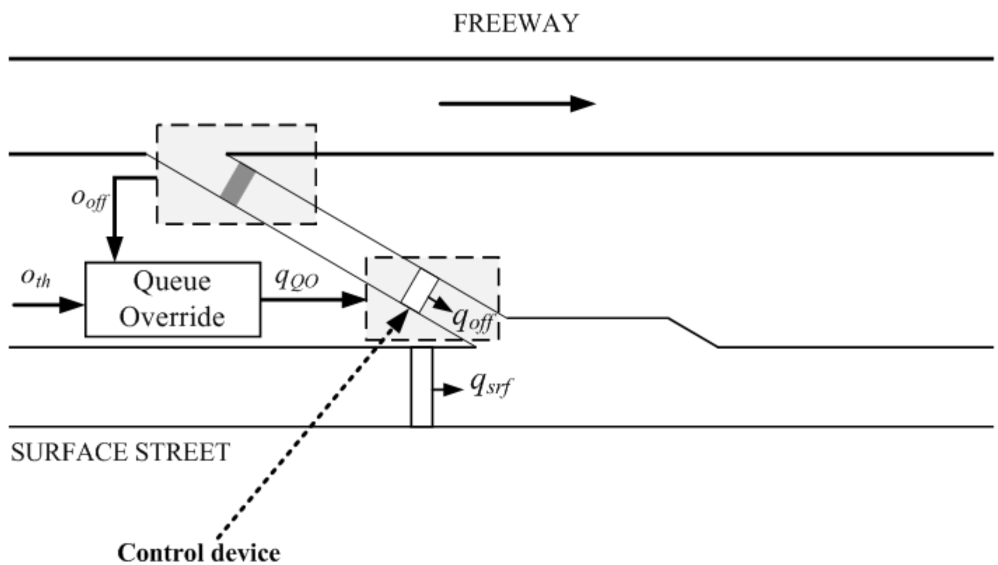


For maximum throughput ➡ $\hat{N} \approx N_{cr}$ (or $\hat{o} \approx o_{cr}$)

Real-time merging traffic control concept
Traffic control algorithm

Queue Override control strategy:

$$q_{QO}(k) = \begin{cases} q_{over}, & if \;\; o_{off}(k-1) > o_{th} \\ 0, & otherwise \end{cases}$$

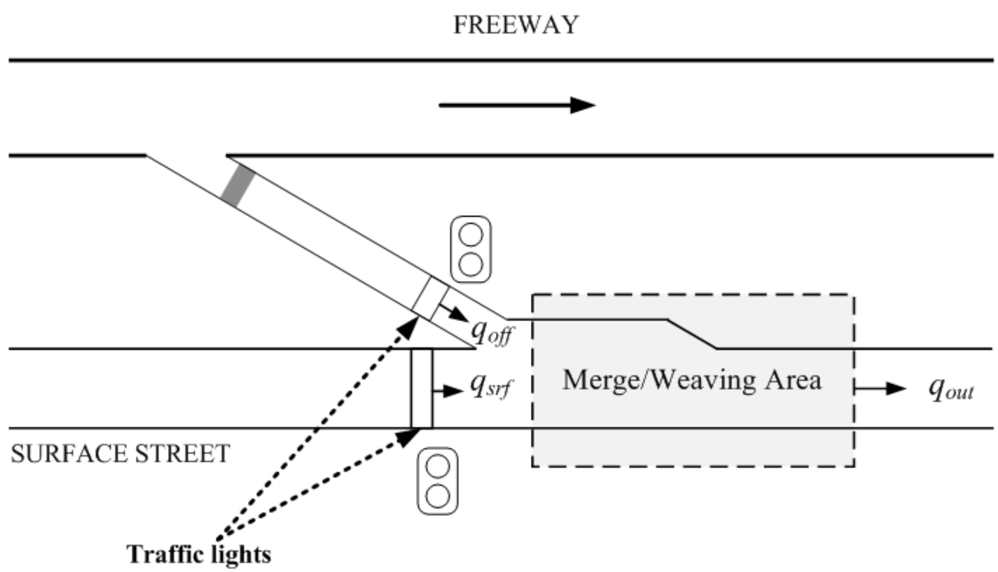


Real-time merging traffic control concept
Traffic control algorithm

Final flow decision:

$$q_{srf}(k) = q_{AL}(k)\lambda_{srf} / \lambda_{total}$$

$$q_{off}(k) = \max\left\{q_{AL}(k)\lambda_{off} / \lambda_{total},\; q_{QO}(k)\right\}$$

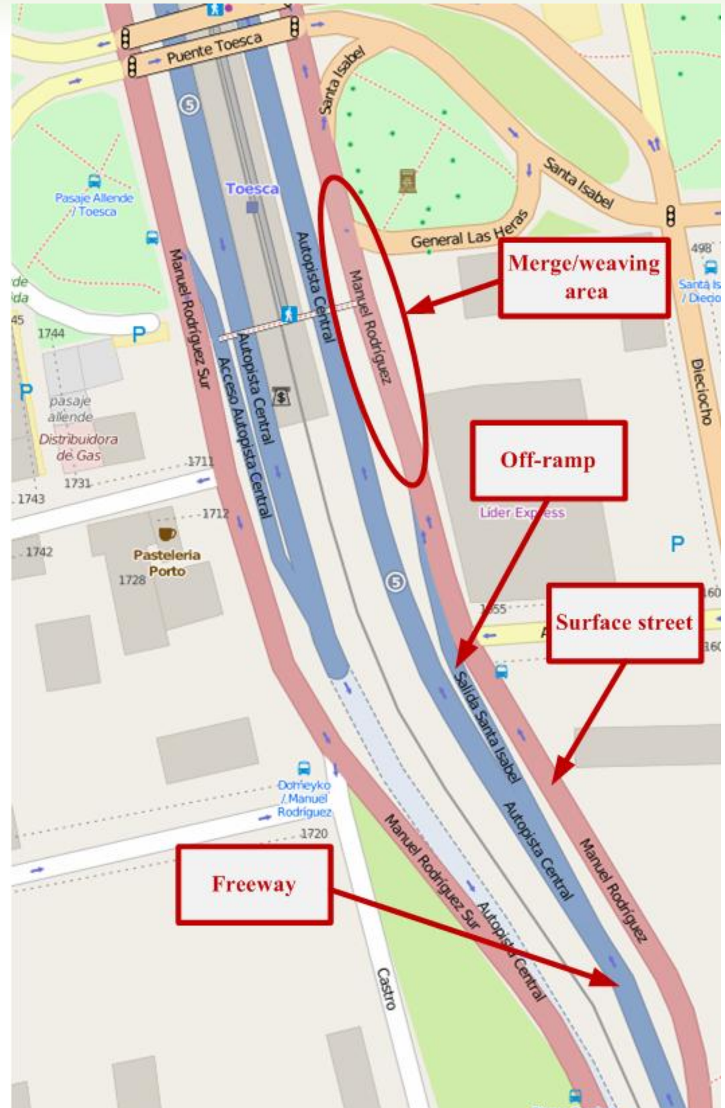


- The final flow decision is implemented through two traffic lights placed at the surface street and the off-ramp upstream of the merge area.

Network description and traffic demand pattern

Autopista Central, Santiago, Chile:

- Congestion during the morning peak hours due to:
  - Limited capacity of the surface street merge area.
  - Strong lane changing maneuvers (weaving) in the merge area.
- This real freeway stretch is utilized to test and demonstrate the application of the proposed control algorithm.



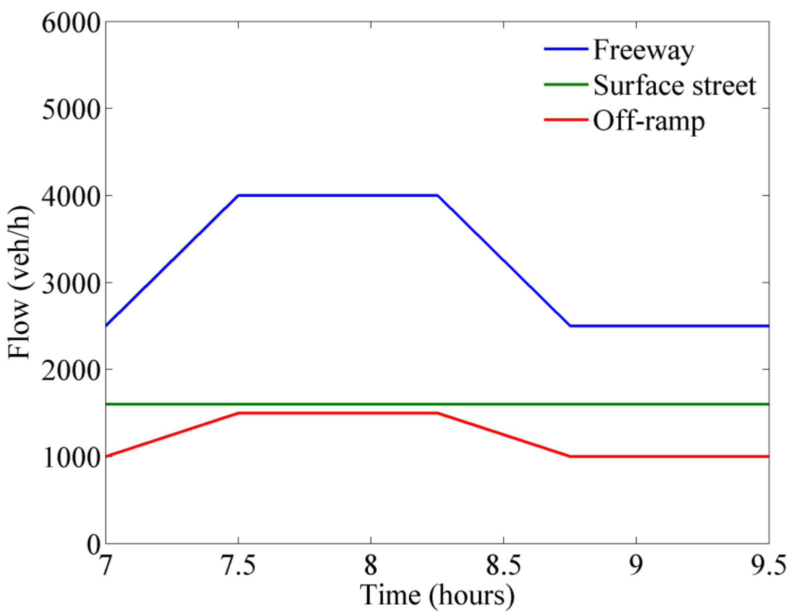
Network description and traffic demand pattern

Microscopic simulation using AIMSUN:

- Freeway stretch: ~7km.
- Surface street network: ~1.52km.
- Detectors at several network locations.

Network description and traffic demand pattern

Microscopic simulation using AIMSUN:

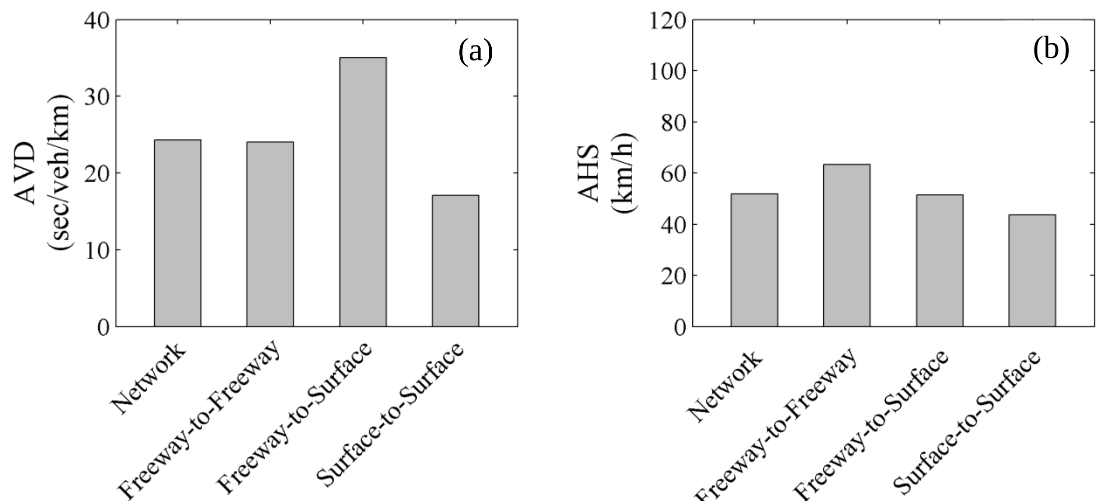


- Average traffic demand similar to the real traffic demand.
- Two vehicle types: cars and trucks.

Simulation investigations
No control case

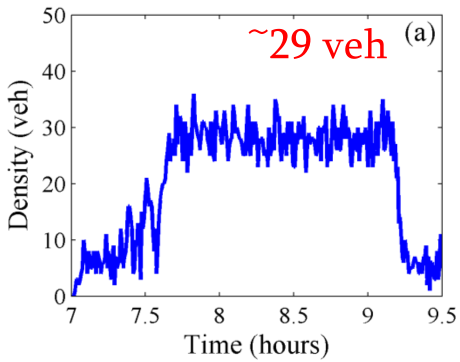
Simulation investigations
No control case

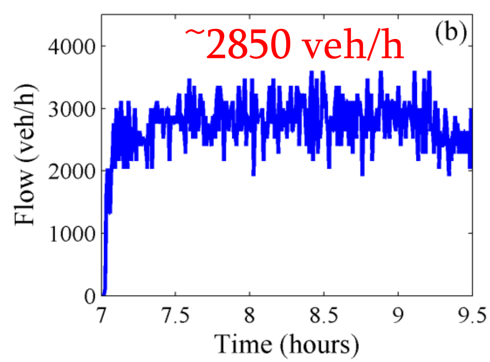
- 10 AIMSUN replications.
- Performance criteria:
  - Average Vehicles Delay (AVD)
  - Average Harmonic Speed (AHS)

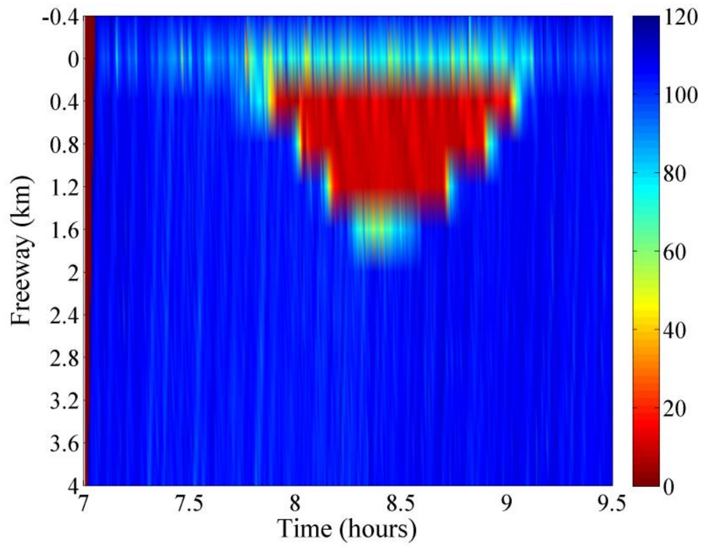


	Network	Freeway-to-Freeway	Freeway-to-Surface	Surface-to-Surface
No Control	24.3	24.0	35.1	17.1

Simulation investigations
No control case





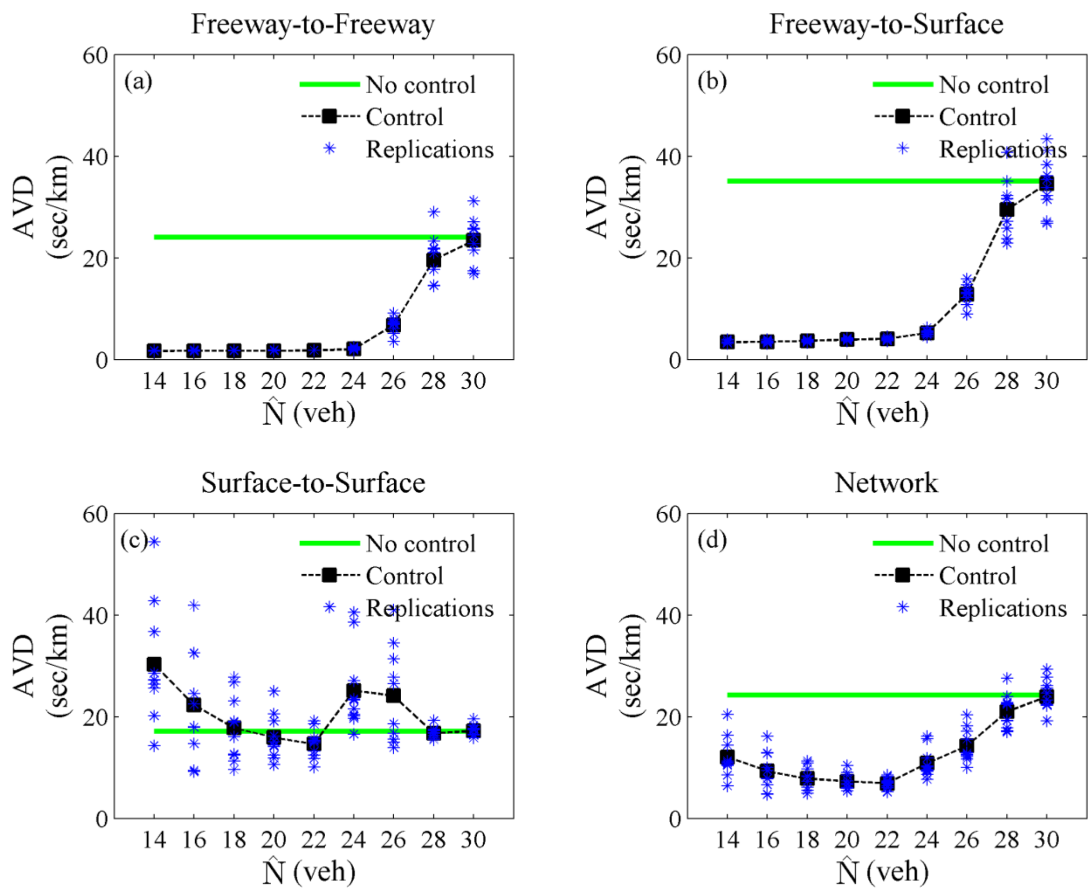


Simulation investigations
Merging traffic control

- ALINEA strategy:
  - $T_c = 30$ s.
  - Input: N.
  - $K_P = 110\ \mathrm{h}^{-1}$, $K_I = 80\ \mathrm{h}^{-1}$.
  - $q_{AL}(k) \in [600,\ 4800]$ veh.
  - $\hat{N} \approx N_{cr}$.
- Queue Override strategy:
  - $T_c = 30$ s.
  - Input: o_{off}
  - $o_{th} \approx 25\%$, $q_{over} = 1600$ veh/h.

Simulation investigations
Merging traffic control

$\hat{N}$-value investigations:

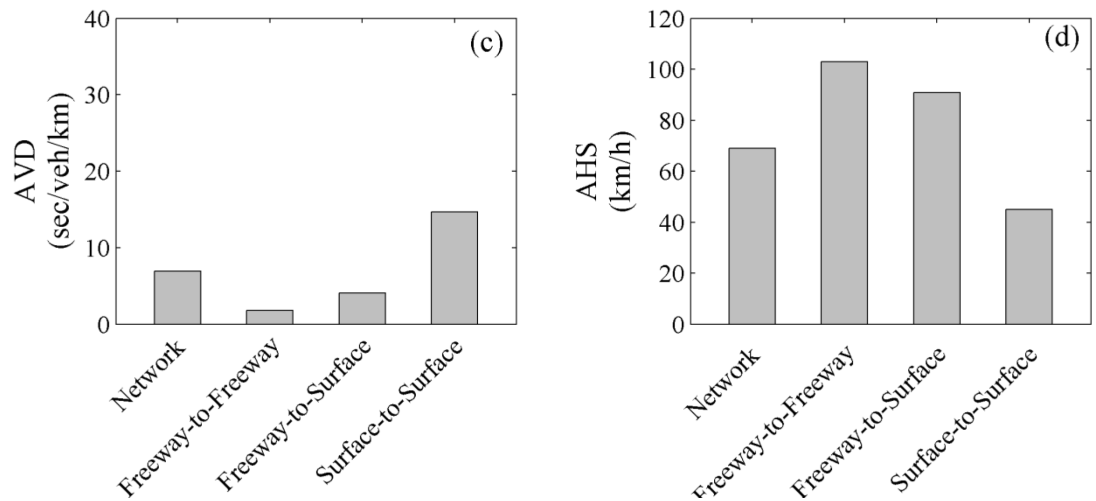


For $\hat{N} \in [20, 22]$ veh → the AVD is minimized.

Simulation investigations

Merging traffic control

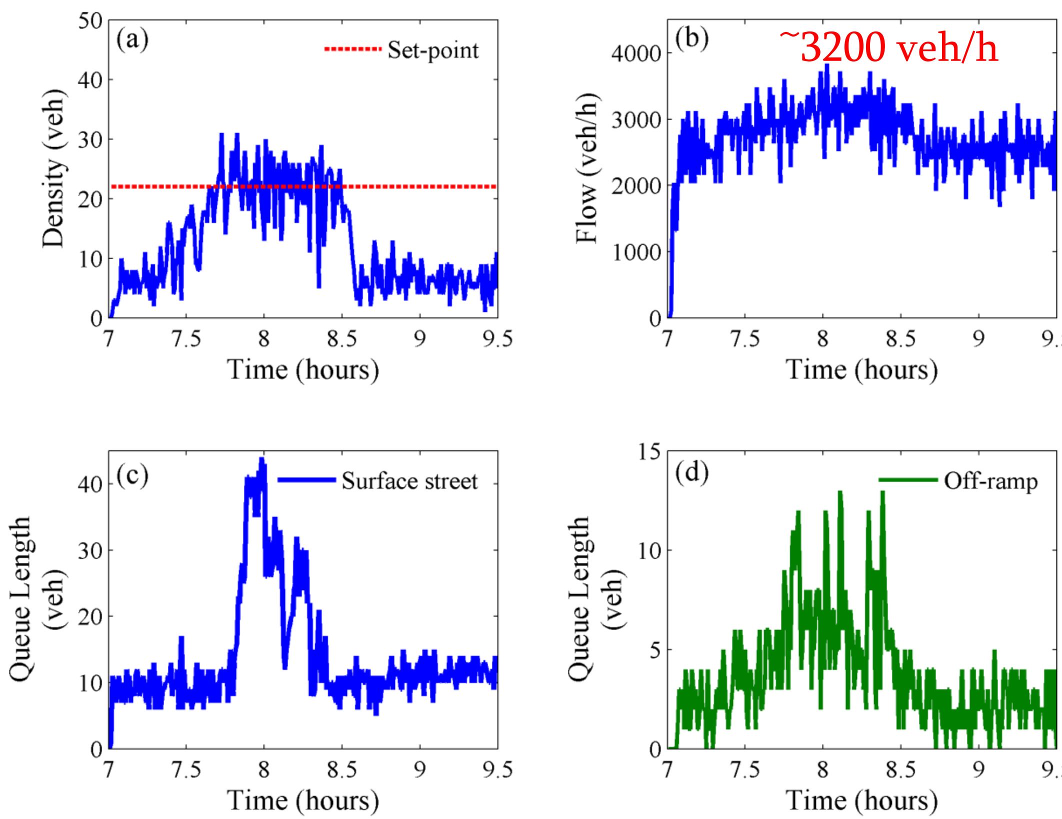
$$\hat{N} = 22 \text{ veh}$$



	Network	Freeway-to-Freeway	Freeway-to-Surface	Surface-to-Surface
No Control	24.3	24.0	35.1	17.1
Control Set-point = 22 veh	6.9	1.8	4.1	14.7
% Difference	-71.6	-92.5	-88.3	-14.0

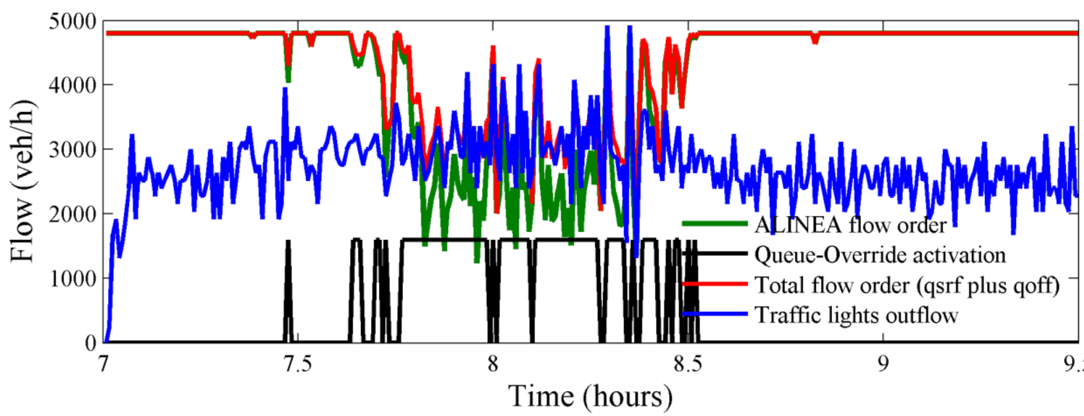
Simulation investigations
Merging traffic control

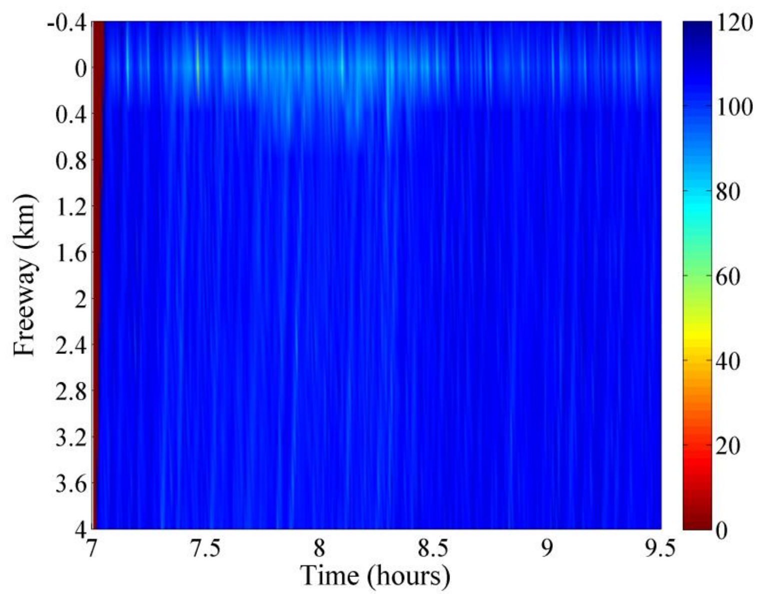
$\hat{N} = 22 \text{ veh}$



Simulation investigations
Merging traffic control

$\hat{N} = 22$ veh





Conclusions and remarks

- A control framework is proposed to address the problem of freeway congestion due to an over-spilling off-ramp.
- The control algorithm aims to maximize the surface street merge area outflow and at the same time to prevent the off-ramp queue spill-over into the mainstream freeway.
- The proposed control concept was demonstrated via microscopic simulation using a real traffic network.
- The simulation results showed that the proposed control algorithm improves the prevailing traffic conditions, preventing the formation of congestion and benefiting both the freeway drivers and the surface street users.

Outline

Introduction

Calibration of Macroscopic Traffic Flow Models

Real-Time Traffic Control Measures : Case 1 – Route diversion control

Real-Time Traffic Control Measures : Case 2 – Merging traffic control

Conclusions and Future Work

Outline

Introduction

Calibration of Macroscopic Traffic Flow Models

Real-Time Traffic Control Measures : Case 1 – Route diversion control

Real-Time Traffic Control Measures : Case 2 – Merging traffic control

Conclusions and Future Work

Conclusions and Future Work

To sum-up:

- The two most popular macroscopic traffic flow models (the CTM and METANET model) were validated and compared regarding the reproduction of traffic conditions at congested freeway off-ramp areas.
- The validation results showed that both models are able to reproduce the traffic conditions in such networks, with the METANET model offering a more accurate representation of the prevailing traffic conditions.
- Two different cases of congested freeway off-ramp areas were examined and innovative traffic control measures were proposed for each investigated case.
- The simulation results showed that in both cases the proposed traffic control strategies manage to prevent the off-ramp queue spill-over and the creation of mainstream congestion thus they are both very promising in case of potential field implementation.

Conclusions and Future Work

Future extensions:

- The utilized traffic flow models, and in particular the CTM model can be extended and improved to increase the achieved accuracy.
- More macroscopic traffic flow models can be employed and compared against the utilized models.
- The first examined traffic control case, for congested freeway off-ramp areas, can be extended in order to account for multiple routes.
- In the second traffic control case, a bigger surface street network can be considered taking also into account possible restrictions that may apply due to signalized junctions.
- Finally, field trial of the proposed traffic control strategies would provide more evidence about the achievable level of benefits.

Publications

International journals:

- **Spiliopoulou, A.,** Kontorinaki, M., Papageorgiou, M.,& Kopelias. P. (2014)
  Macroscopic traffic flow model validation at congested freeway off-ramp areas
  Transportation Research Part C, Vol. 41, pp. 18–29.
- **Spiliopoulou, A.,** Kontorinaki, M., Papamichail, I., & Papageorgiou, M. (2015)
  Real-time route diversion control at congested freeway off-ramp areas.
  Transportation Research Part C (under review).
  Spiliopoulou, A., Papageorgiou, M. (2015)
  Real-time merging traffic control at congested freeway off-ramp areas (under preparation).

Conferences:

- **Spiliopoulou, A.,** Kontorinaki, M., Papageorgiou, M. & Kopelias, P. (2013)
  Συγκριτική αξιολόγηση μακροσκοπικών μοντέλων κυκλοφορίας σε περιοχές ραμπών εξόδου αυτοκινητοδρόμων (Comparative evaluation of macroscopic traffic flow models in freeway off-ramp areas)
  6ο Συνέδριο για την Έρευνα στις Μεταφορές στην Ελλάδα (6th Congress on Transportation Research in Greece), Thessaloniki, Greece, October 17–18.
- **Spiliopoulou, A.**, Kontorinaki, M., Papamichail, I., & Papageorgiou, M. (2013)
  Real-time route diversion control at congested off-ramp areas - Part II: Route guidance versus off-ramp closure.
  EWGT2013 – 16th Meeting of the EURO Working Group on Transportation, Porto, Portugal, September 4-6.
- **Spiliopoulou, A.**, Kontorinaki, M., Papamichail, I., & Papageorgiou, M. (2013)
  Real-time route diversion control at congested motorway off-ramp areas – Part I: User-optimum route guidance
  Proc. of the 16th International IEEE Annual Conference on Intelligent Transportation Systems, The Hague, The Netherlands, October 6–9.

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Thank you for your attention!