Progress Report (July 2019)

- Integrated control strategy for variable speed limits and ramp metering by METANET
- Smart freeway data processing and analysis
- Work in progress: optimization of dynamic motorway traffic with robust joint-chance constraints via ramp metering

Integrated control strategy for Variable speed limits (VSL) and ramp metering (RM) by METANET

Project PhD Student: S Xu
Project Supervisor: B Wiwatanapataphee

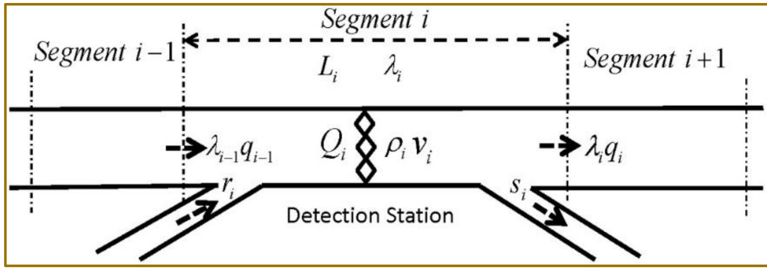
- Introduction
- METANET simulation model
- Simulation realisation
- Test example and discussion

Introduction

-- Underlying mathematical model

- Conservation equation:

$$\rho_i(k+1) = \rho_i(k) + \frac{T}{L_i\lambda_i}(\lambda_{i-1}q_{i-1}(k) - \lambda_i q_i(k) + r_i - s_i)$$



- Traffic flow equation: $q_i(k) = \rho_i(k)v_i(k)$
- Mean speed dynamics on the basis of static speed-density relationship:

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

Relaxation Convection Anticipation

$$V[\rho_i(k)] = v_{free}\, exp\left[-\frac{1}{\alpha}\left(\frac{\rho_i(k)}{\rho_{cr}}\right)^{\alpha}\right]$$

$b_i(k)$

- On- and off-ramps:

$c_i(k)$

$$r_i(k) = min\left\{d_{ramp}(k) + \frac{\omega_{ramp}(k)}{T}, Q_{max,ramp}, Q_{max,ramp}\left(\frac{\rho_{jam,i} - \rho_i(k)}{\rho_{jam,i} - \rho_{cr}(k)}\right)\right\}$$

$$\omega_{ramp}(k+1) = \omega_{ramp}(k) + T\left[d_{ramp}(k) - r_i(k)\right]$$

Introduction

-- METANET software

- “A simulation program for motorway networks”
  - ✓ Low computational cost
  - ✓ Applicable to various scenarios:
    - Free/ dense/ congested;
    - Incidents.
  - ✓ Applicable to arbitrary network topology and geometric characteristics
  - ✓ Report in terms of macroscopic traffic variables
    - Traffic density;
    - Traffic volume;
    - Mean speed;
    - Travel times on selected routes.
  - ✓ Visualisation
    - Time-series evolution of selected variables;
    - Graphical representation of the entire network

METANET simulation model

-- Key elements

- Network representation by Graphs with nodes and links
  - Nodes: on/off ramps, junctions etc
  - Link: a road segment between two nodes
- Required Traffic Data
- Incidents (Control Events and Incidents file)
- Control measures modelling (Control Measures Parameter file)
- Calculation of global performance criteria
  - Total travel time;
  - Total waiting time (in the queues of the origin links and of the store-and-forward links);
  - Total distance travelled;
  - Total amount of fuel assumed; and
  - Total disbenefits of routed drivers

METANET simulation model

-- Key elements

Nodes

- Bifurcations
- Junctions
- On/ off ramps
- Change of geometry

Splitting rate/ Average route choice behaviour of travellers

Links

- Normal motorway link
- Dummy link
- Store-and-forward link
- Origin link
- Destination link

Normal motorway link:
- Subdivisions: 300~800-metre segment)
- Traffic variable updating interval: 10s
- Link-specific traffic dynamics: Fundamental diagram

Dummy link:
- Zero length
- No own dynamics

Store-and-forward link:
- Traffic behaviours:
  - A constant travel time;
  - A waiting queue model;
  - Outflow limitations

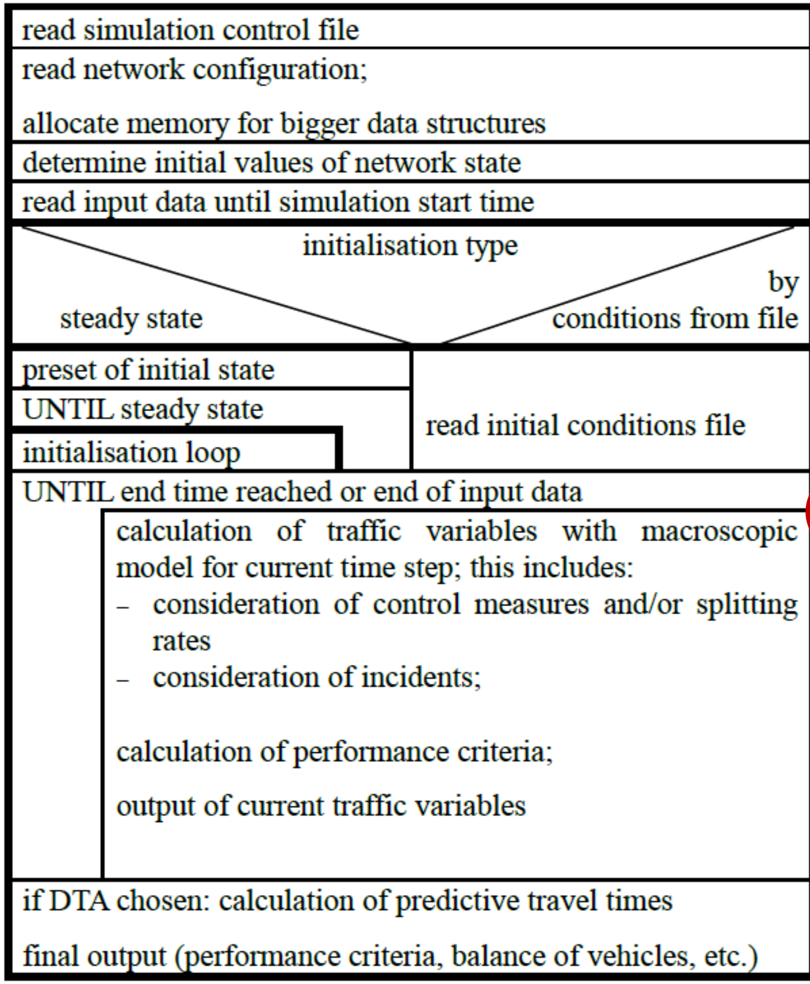
METANET simulation model

-- Key elements

- Parameters for certain control measures:
  - Compliance rate;
  - Feedback parameters;
  - FM parameter sets;
  - Resulting capacities
- Specification of incidents:
  - Occurrence time and duration;
  - Location;
  - Severity
- Concurrency of incidents and control measures

Simulation realization by METANET

-- Program structure



- *ctrname*.ctr
- *nwdname*.nwd
- *smdname*.chk

Initial state definition

- (*nwdname*.ini)

With steady-state conditions according to boundary conditions (mainly network inflows) valid at the beginning of simulation

- (*nwdname*.ico)

With user-specified values

Updating traffic data

- *trdname*.*

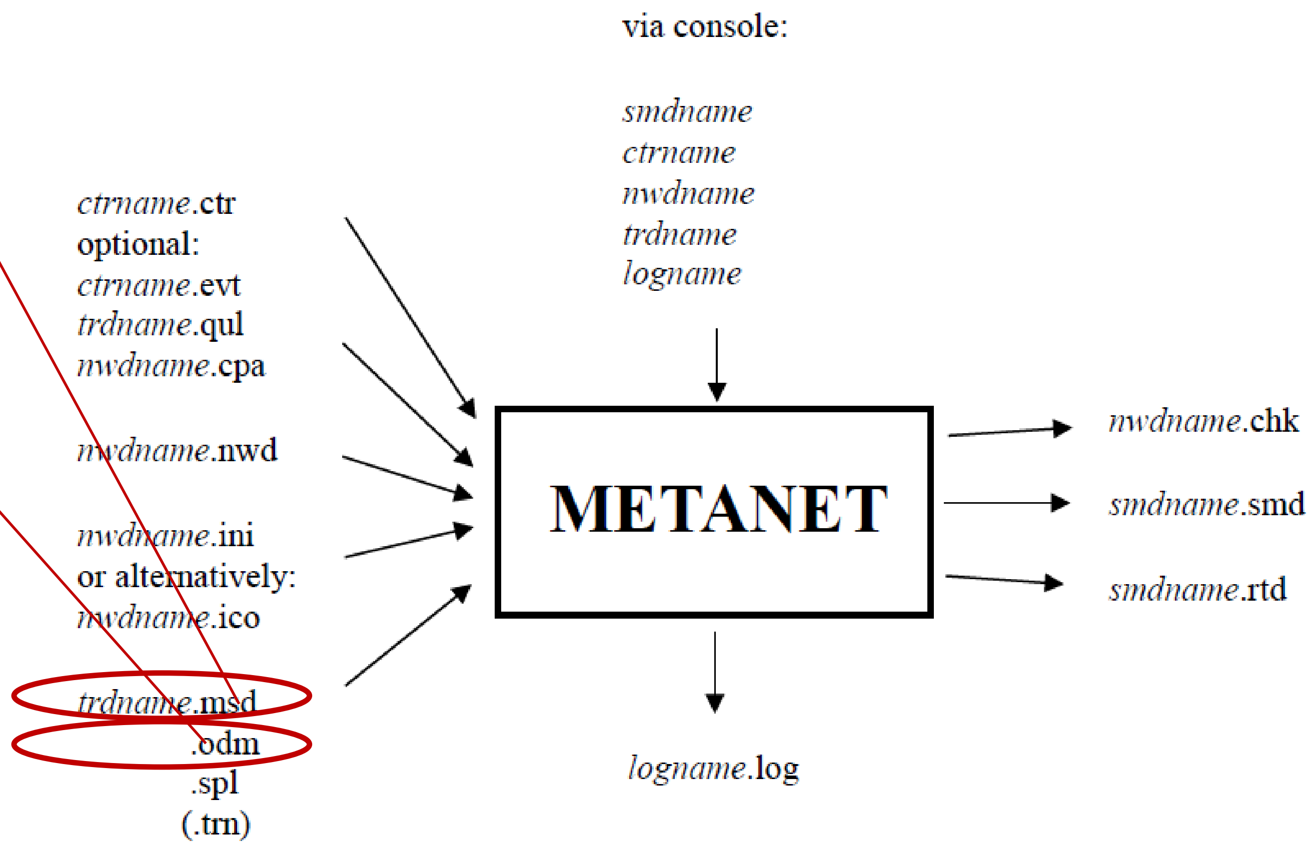
- *smdname*.smd

Simulation realization by METANET

-- Program inputs & outputs

- **Traffic data files**
- Boundary data
  - Demands (inflows into the network);
  - Origin-destination information
- Splitting/ Turning rates

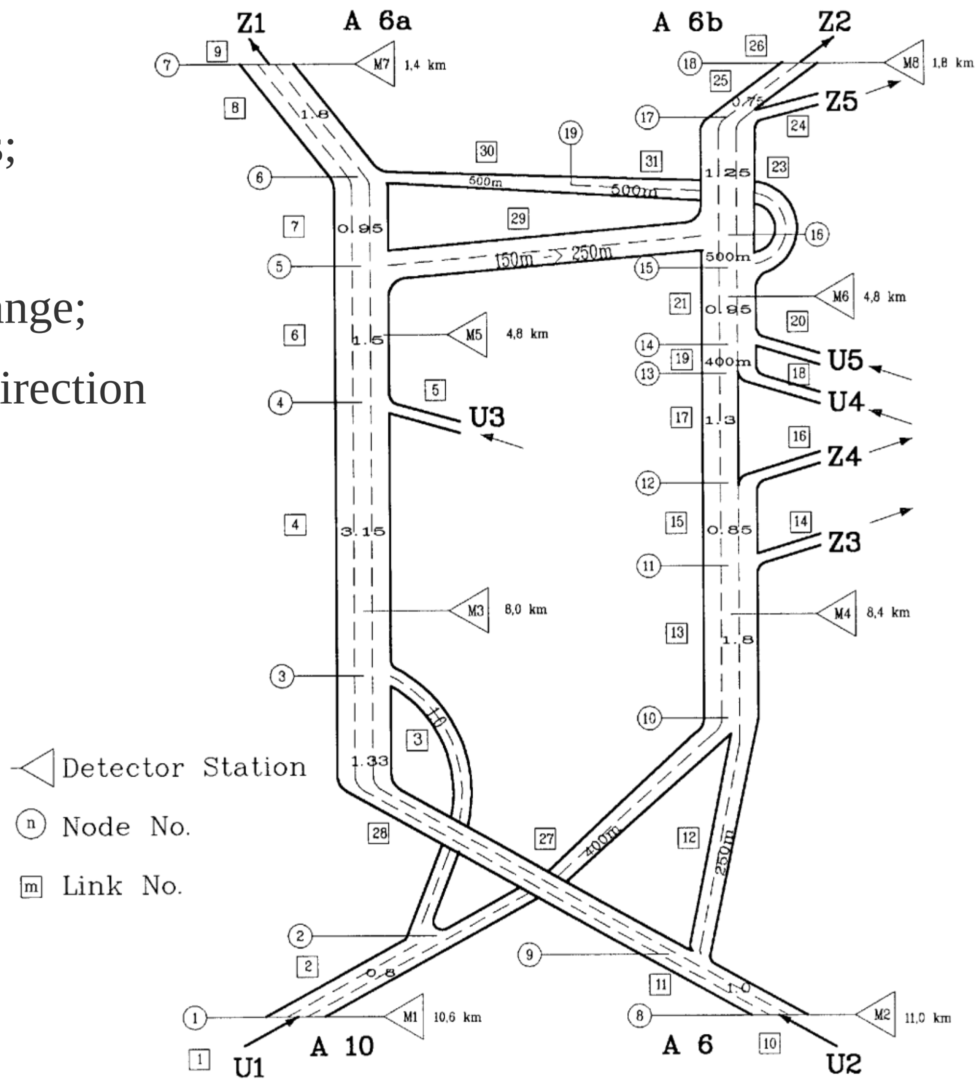
- All files are of type text (ASCII)



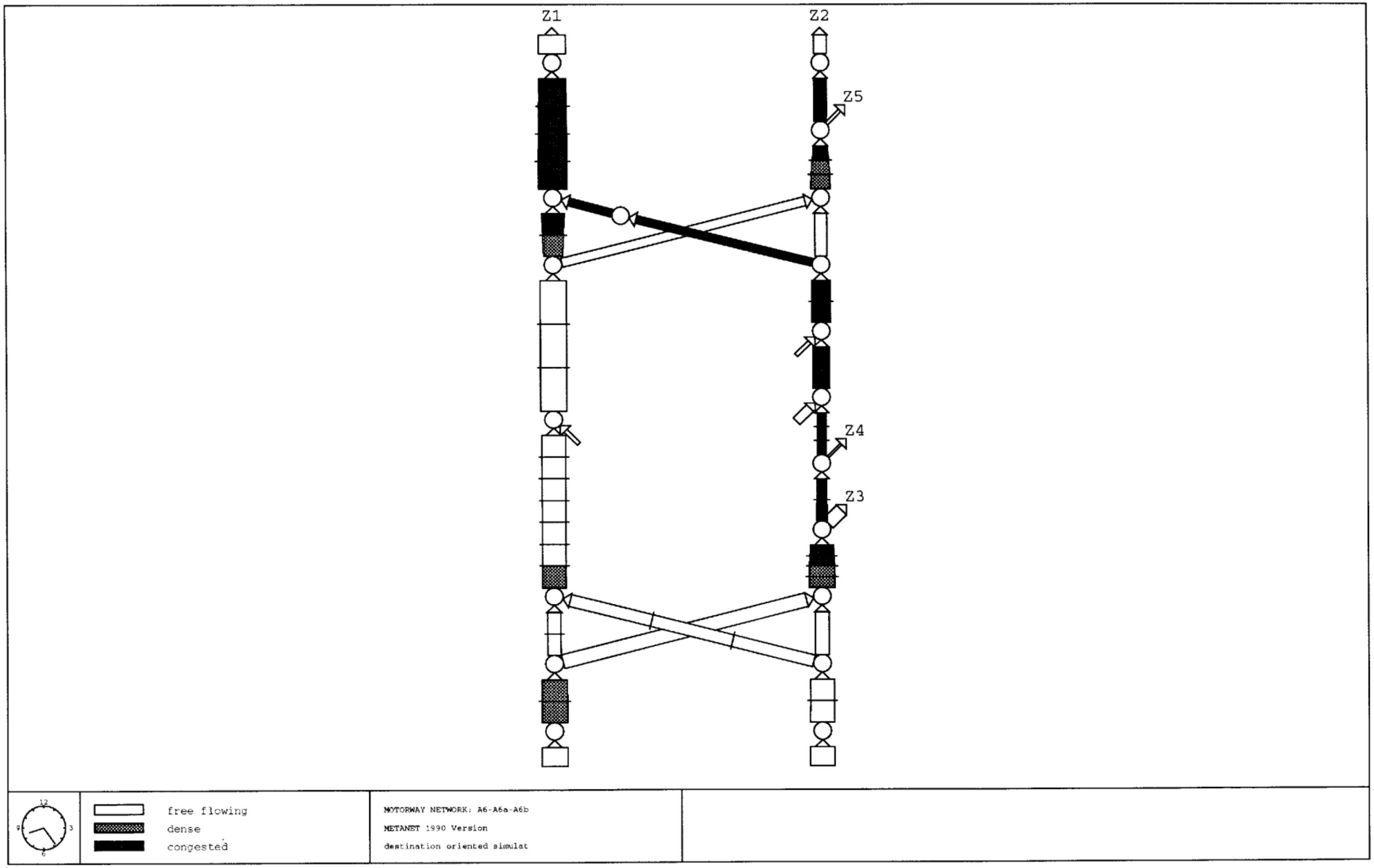
Test example

- Two parallel motorway axes;
- Several on- and off-ramps;
- Two possibilities of interchange;
- Consider only northbound direction

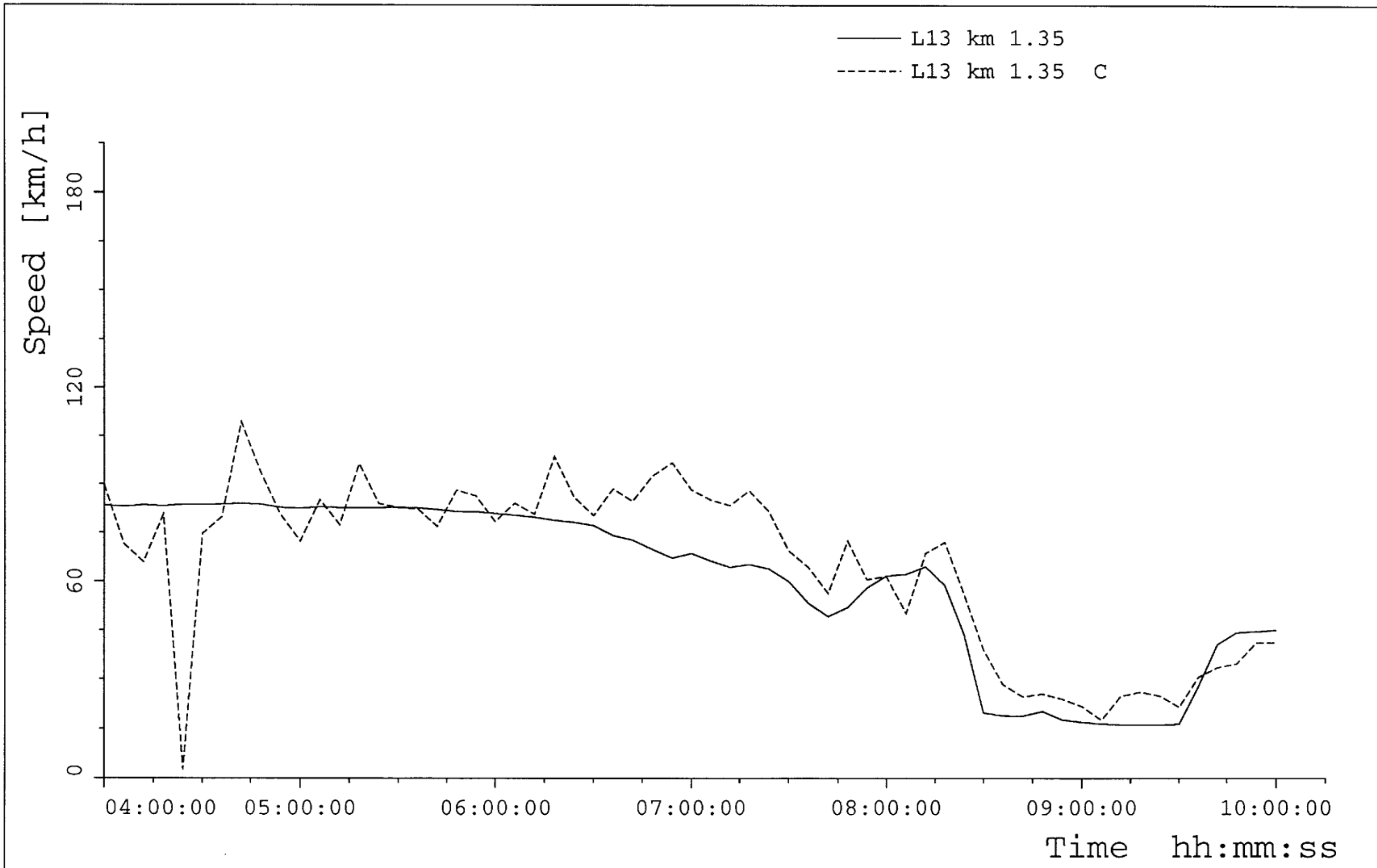
- 21 links (45 segments);
- 19 nodes;
- 5 origins;
- 5 destinations



Test example -- Results



Test example -- Results



Test example -- Discussion & Conclusion

- METANET can only present time trajectories of traffic speed;
- METANET alone cannot solve optimisation problems;
- METANET, together with AMOC module, cannot realise real-time decision makings;
- Package of METANET & AMOC is not openly available.

METANET ?

- SUMO is mainly a microscopic simulation package and possible for macroscopic and mesoscopic applications;
- SUMO is open source with a wide range of extensions.

SUMO

Smart freeway data processing and analysis

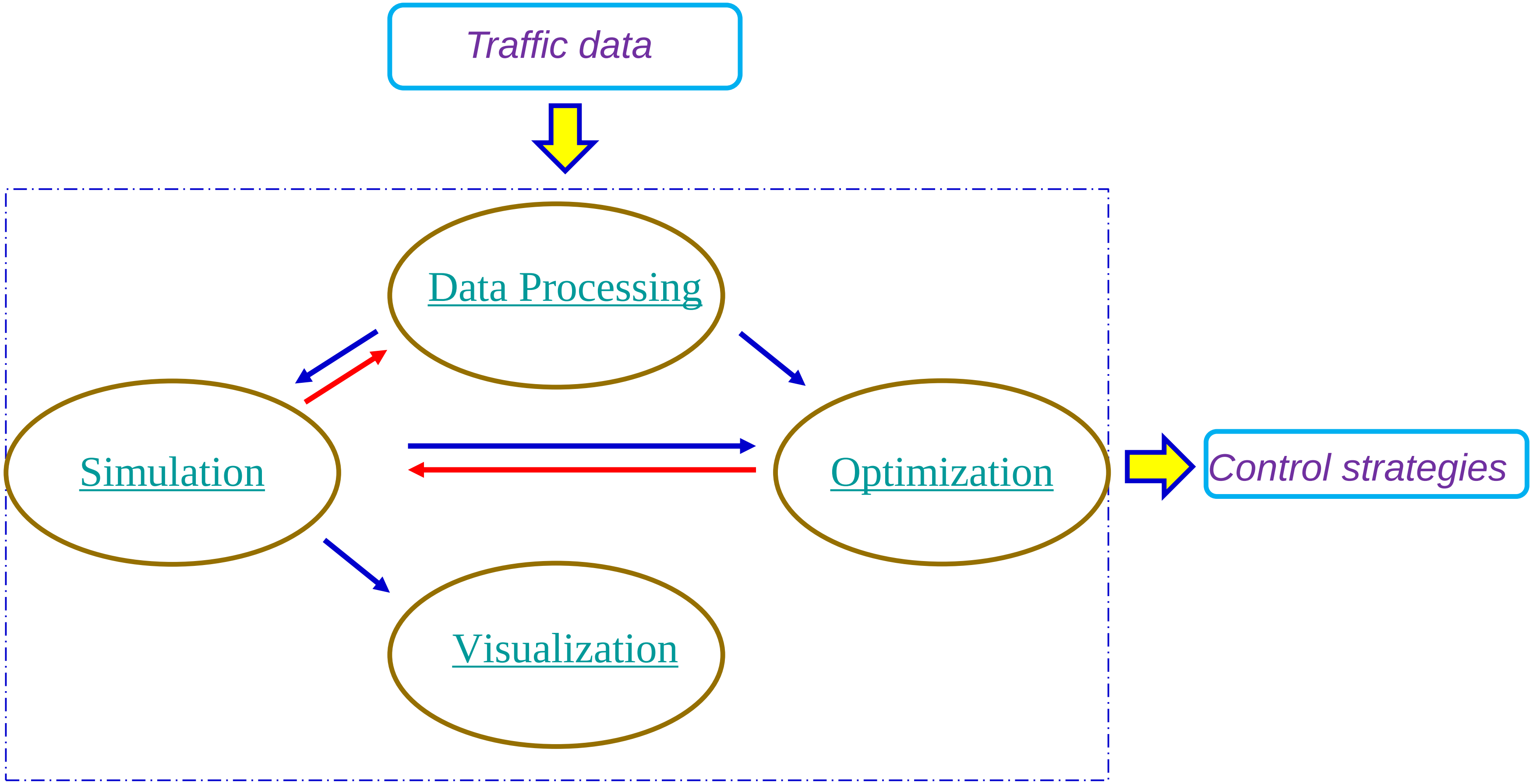
Project researcher : Shican Liu
Project Supervisors: YH Wu & B Wiwatanapataphee

- Introduction
- Traffic Demands onto freeway through on-ramps
- Traffic Density, Velocity, Flow rate on freeway links
  - KwN Fwy NB from Manning Rd to Canning Hwy
- Traffic Density, Velocity, Flow rate on freeway links
  - KwN Fwy NB from Mill Point Road

Return

1. Introduction

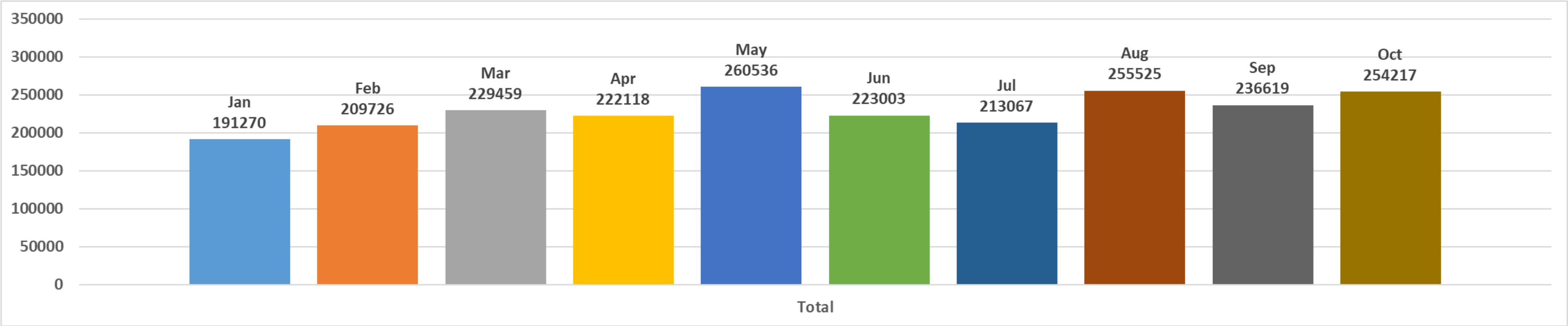
A computational framework for smart freeway modelling and optimization

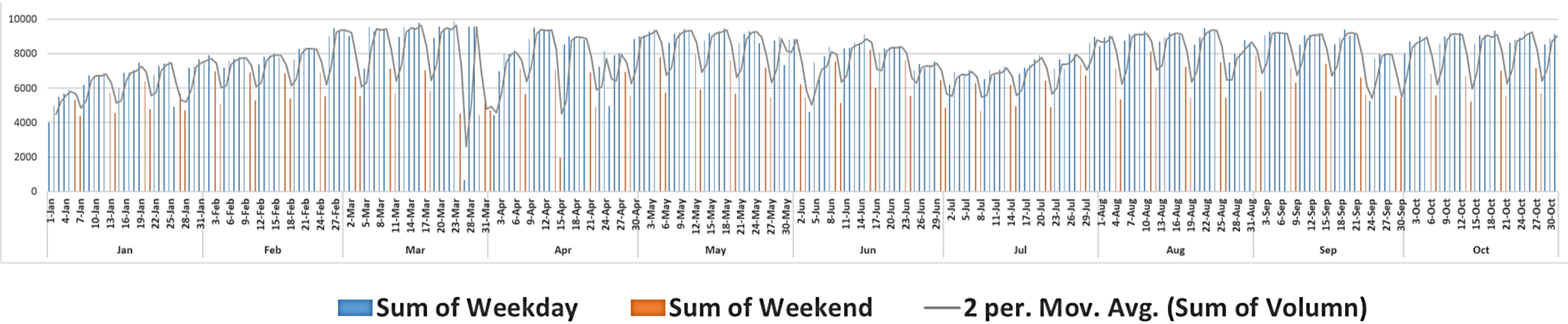


2. Traffic Demands onto freeway through on-ramps

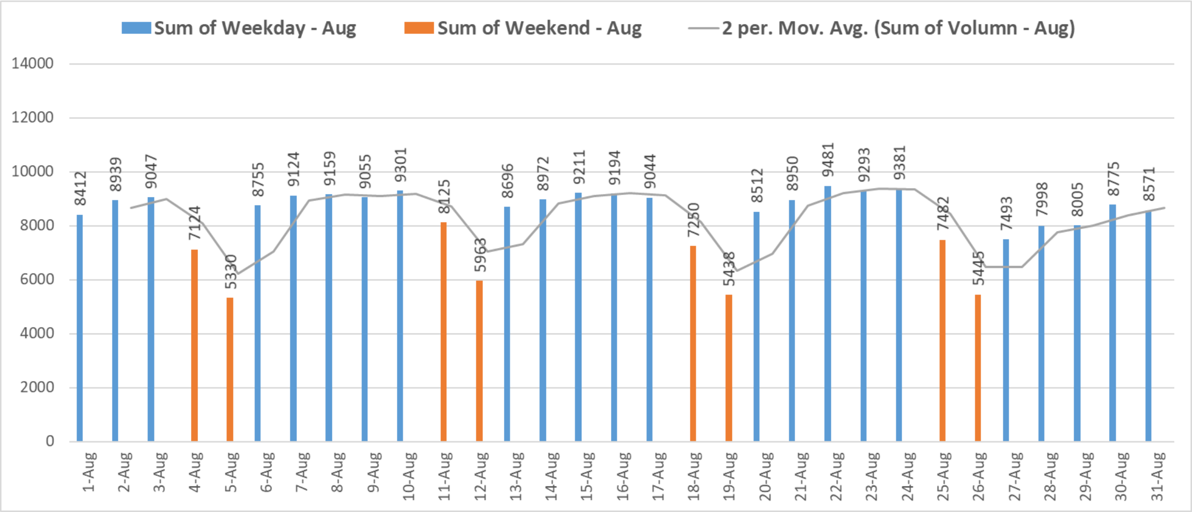
KwN Manning On-Ramp (130) (H457@310) – 0130KWN-OR1

Traffic Volume (Jan – Oct 18)

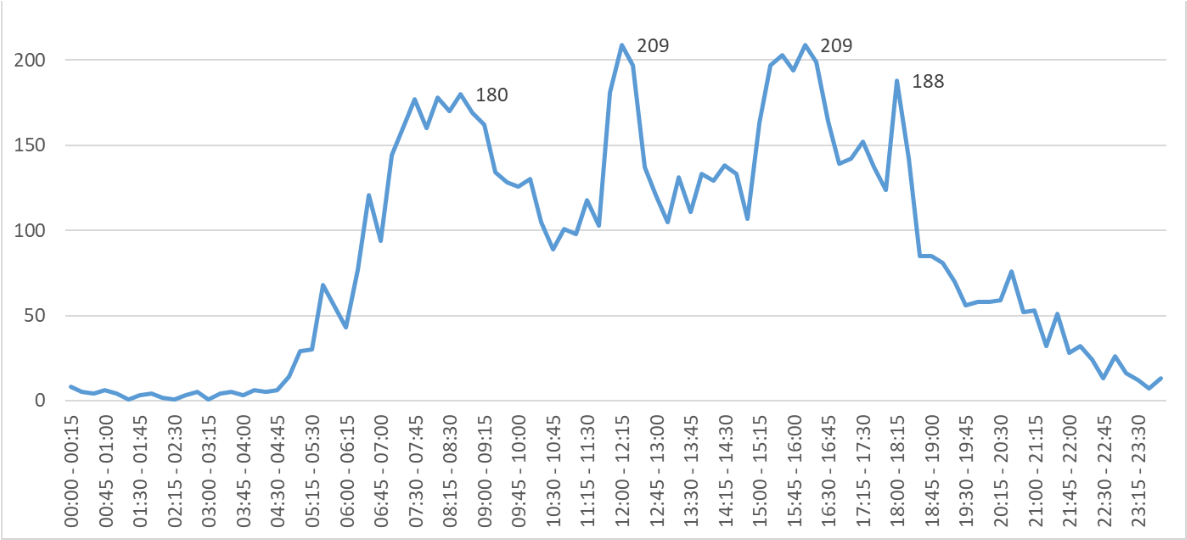




Distribution of daily traffic volume in August 2018

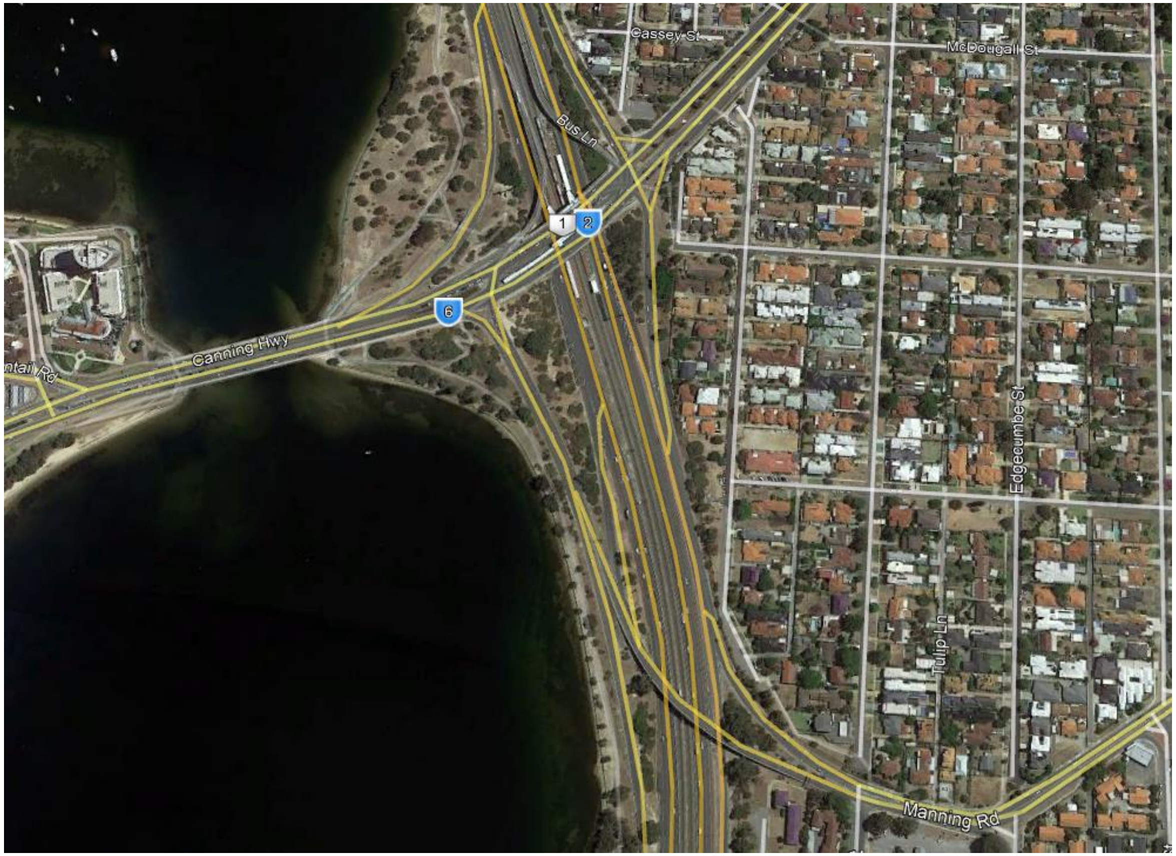


Distribution of flow rate (veh/15 mins) in a typical day (1 August 2018)



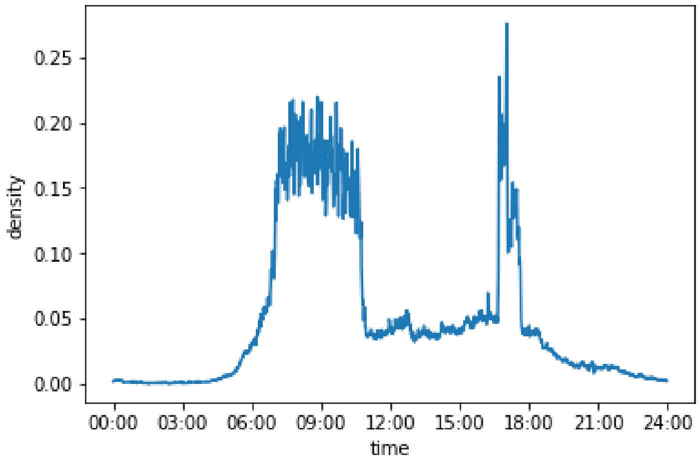
3. Traffic Density, Velocity, Flow rate on Freeway links

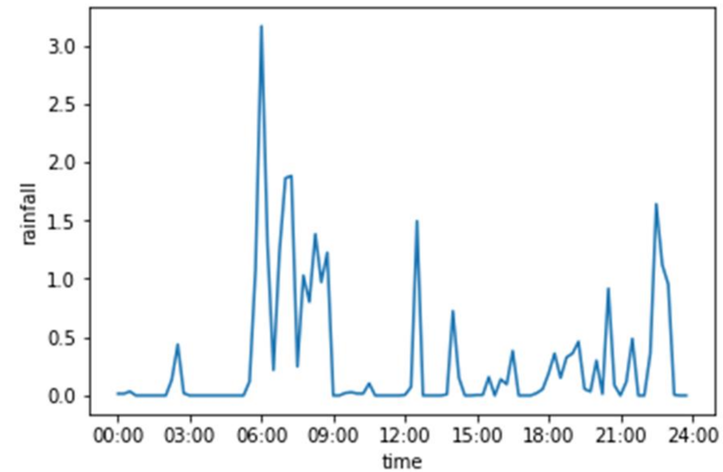
Kwinana Fwy Nth Bound between Manning Rd - H547 on KwN Fwy NB &
Canning Hwy - H549 on Kwy Fwy

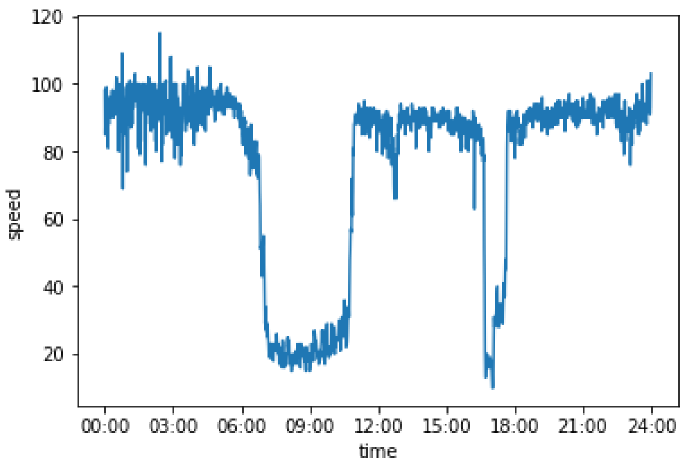


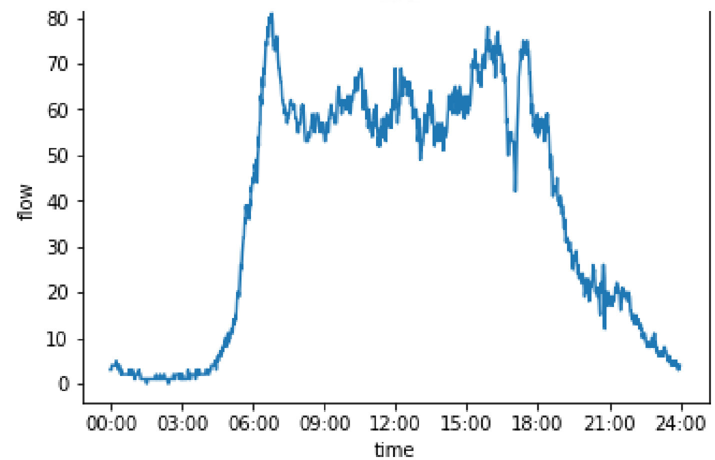
Variation of traffic density, speed, flow rate and rainfall

On a typical raining day (1 August 18)









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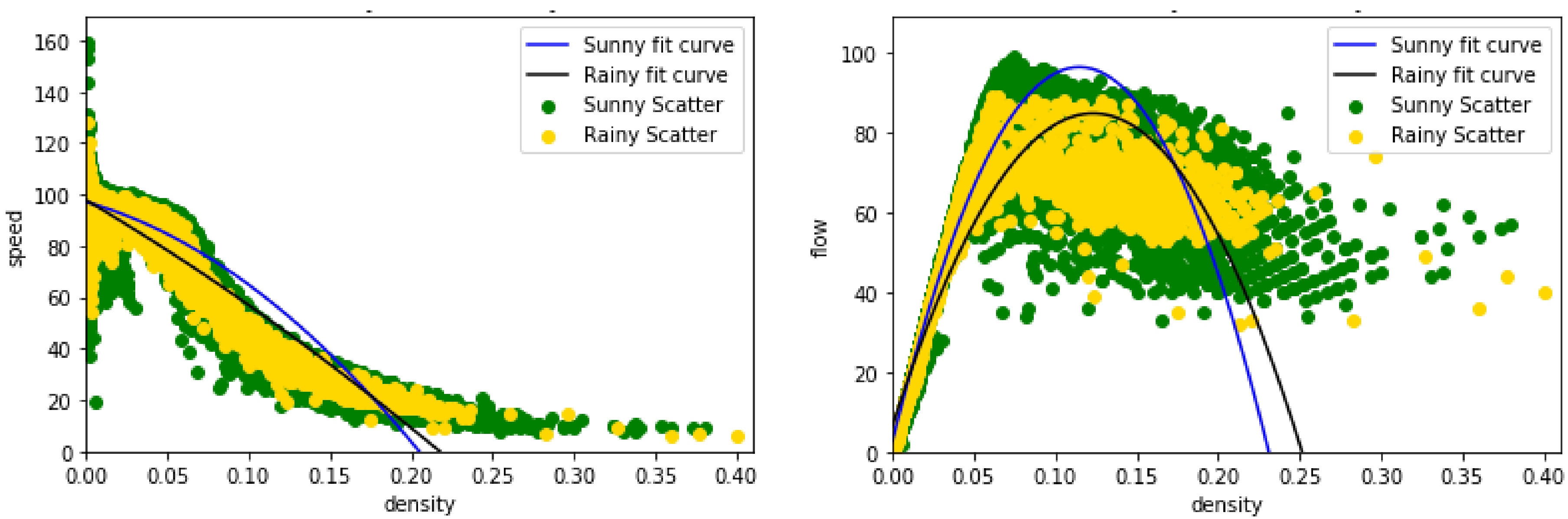
Relationship between Speed (km/hr)/Flow (veh/min) and Density (veh/metre) Jan – Oct 2018

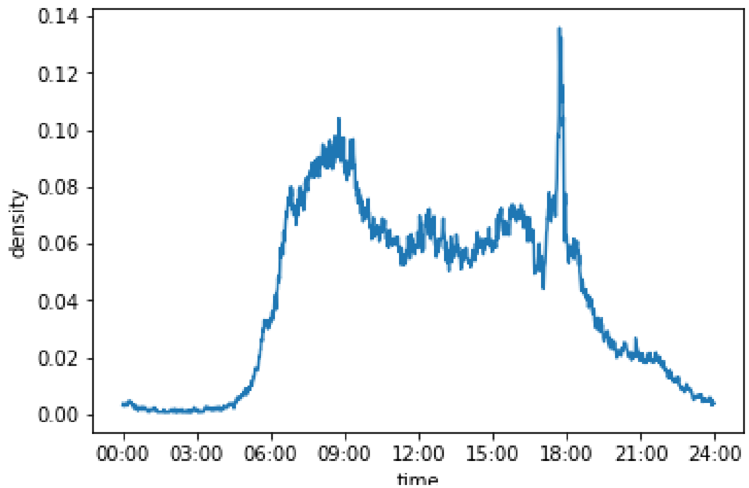


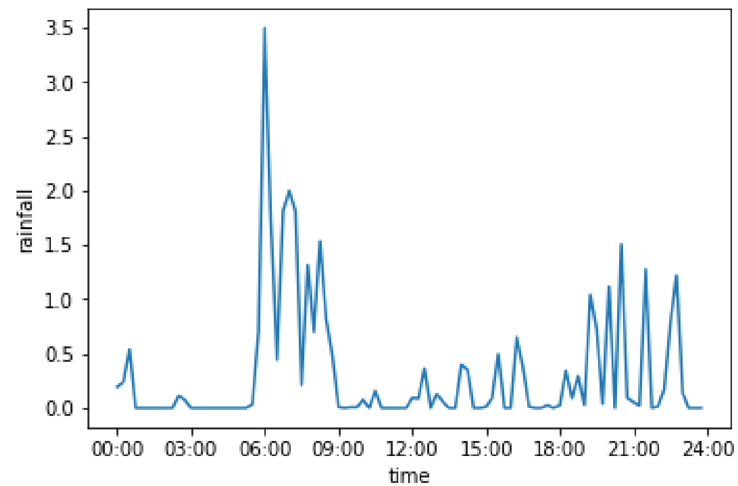
4. Traffic Density, Velocity, Flow rate on freeway links

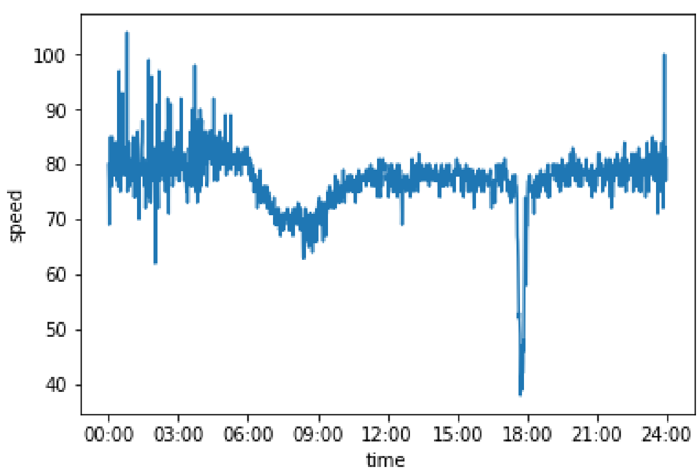
Kwinana Fwy NB between Kwinana Fwy Nth Bound H503 Off - Mill Pt Rd & Mitchell Fwy Nth Bound

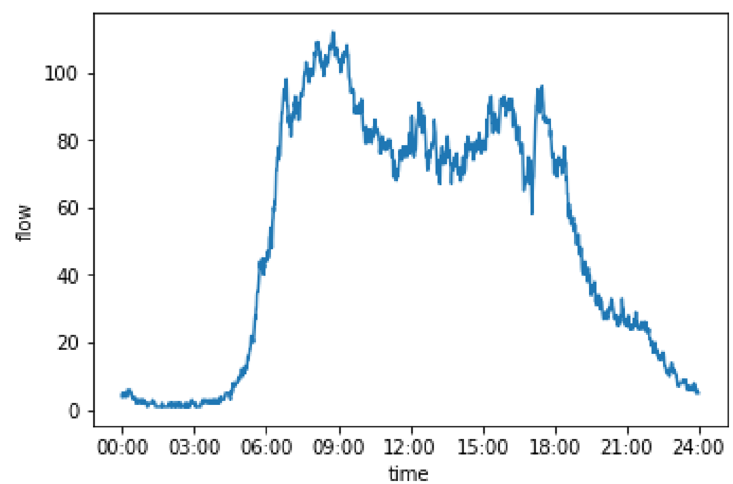
Variation of traffic density, speed, flow rate and rainfall

On a typical raining day (1 August 18)

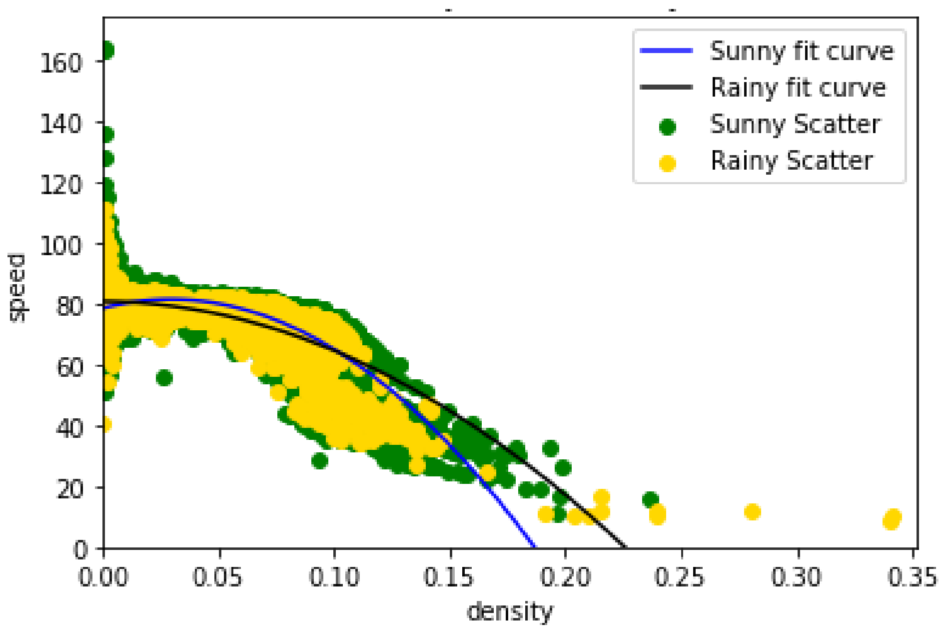


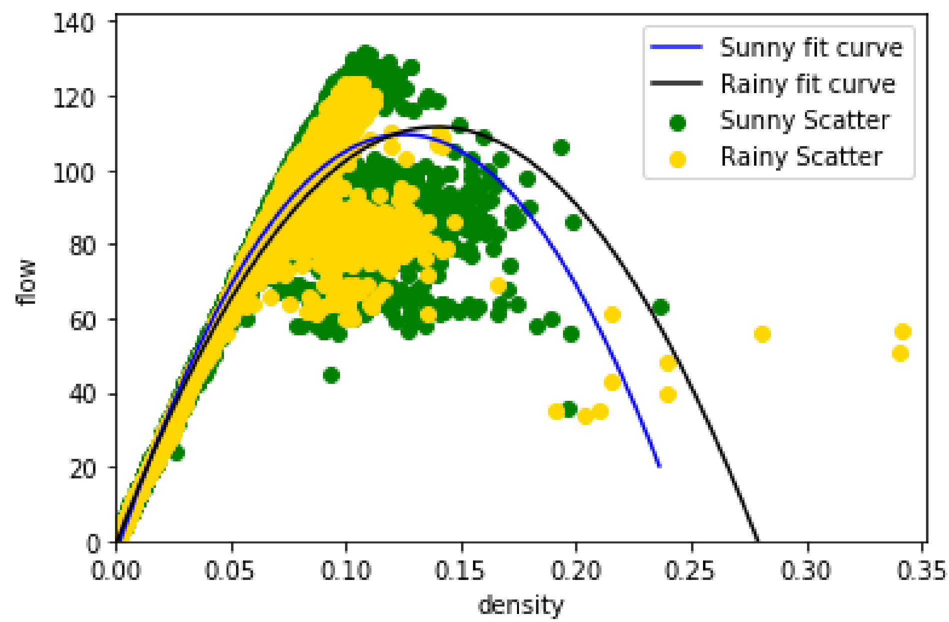






Relationship between
Speed (km/hr)/Flow (veh/min) and Density (veh/metre)
Jan – Oct 2018





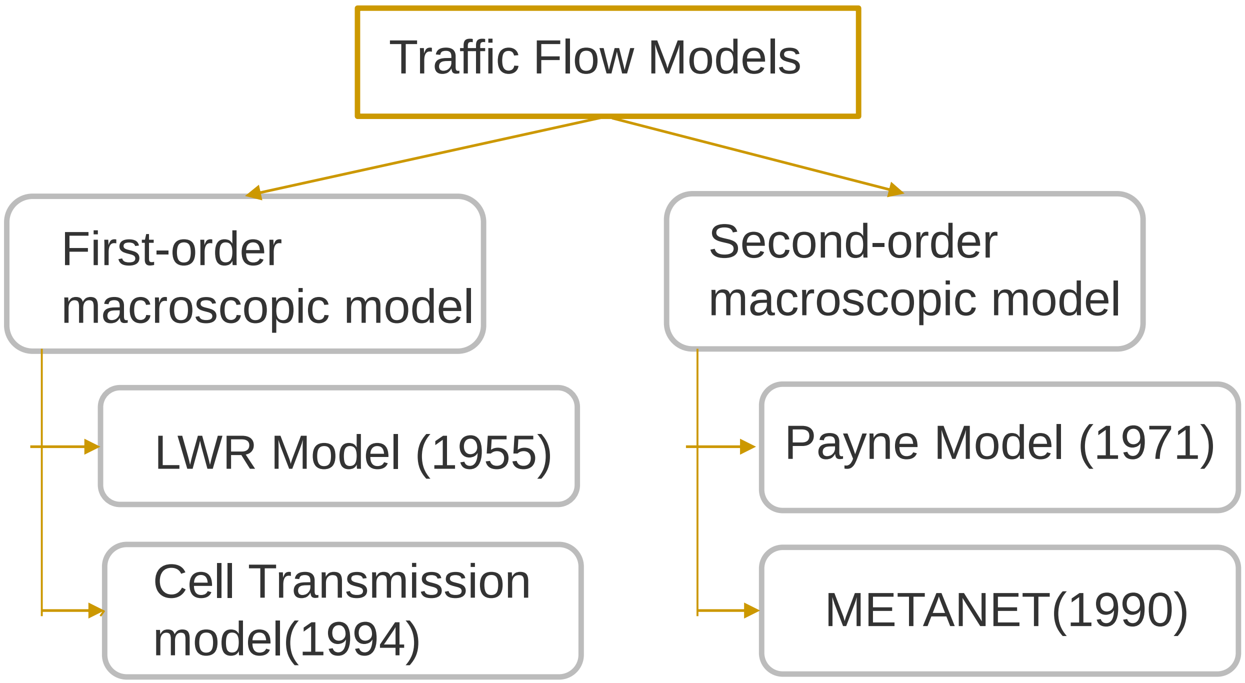
Work in Progress:
Optimization of dynamic motorway traffic with robust joint-chance constraints via ramp metering

Project PhD student: Chuanye Gu
Project Supervisors: YH Wu & B Wiwatanapataphee

- Introduction
- Traffic Flow Dynamics
- Robust Optimization model based on CTM

Introduction

- Classification of Macroscopic Traffic flow models

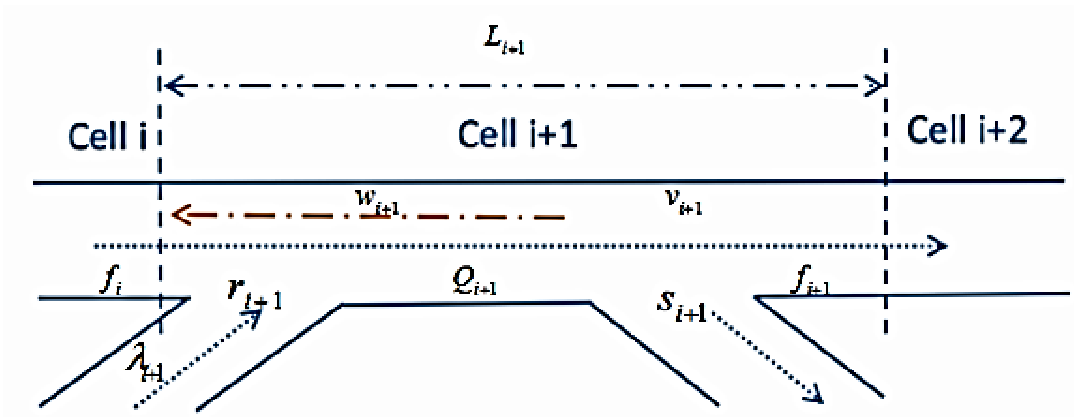


Traffic Flow Dynamics (CTM)

- Kinematic Wave Model or LWR model

$$\frac{\partial \rho_{x,t}}{\partial t} + \frac{\partial f_{x,t}}{\partial x} = r_{x,t} - s_{x,t}$$

- Cell Transmission Model (CTM)



$$\rho_{i,t+1} = \rho_{i,t} + \frac{\triangle t}{\triangle x_i}\left(f_{i-1,t} - f_{i,t} + r_{i,t} - s_{i,t}\right)$$

and

$$f_{i,t} = \min\left\{v_i \rho_{i,t},\ Q_i,\ Q_{i+1},\ w_{i+1}(\bar{\rho}_{i+1,t} - \rho_{i+1,t})\right\}$$

Distributionally Robust Optimization based on CTM

Assume that the uncertain demand and capacity depend affinely on the random number $\xi \in R$ and $\zeta \in R$, i.e.,

$$\tilde{\lambda}_{j,t} = \mu_{j,t} + \delta_{j,t}\xi$$

$$\tilde{Q}_i = \theta_i + \eta_i\zeta$$

where $\mu_{j,t}$ and θ_i denote the means of the demand and capacity, and $\delta_{j,t}$ and η_i denote the variances of demand and capacity with

$$E(\xi) = 0,\ E(\zeta) = 0,\ Var(\xi) = 1 \text{ and } Var(\zeta) = 1.$$

Constraint optimization problem:

$$(\mathrm{DRP})\min_r D \;=\; \sum_{i=1}^{I}\sum_{t=1}^{T}\left(\rho_{i,t}\triangle x_i \triangle t - \frac{f_{i,t}\triangle x_i \triangle t}{v_i}\right) + E\left(\sum_{j=1}^{J}\sum_{t=1}^{T}\ell_{j,t}\triangle t\right)$$

subject to

$$\rho_{i,t+1} = \rho_{i,t} + \frac{\triangle t}{\triangle x_i}\left(f_{i-1,t} - f_{i,t} + r_{i,t} - s_{i,t}\right), \quad \forall i, t$$

$$\left\{\begin{array}{l} f_{i,t} \le v_i \rho_{i,t}, \forall i, t, \\ \inf_{\mathbb{P}\in\mathbf{P}} \mathbb{P}[f_{i,t} - \theta_i - \eta_i \zeta, \forall i, t,] \ge 1 - \epsilon_c, \end{array}\right\} \text{send function,}$$

$$\left\{\begin{array}{l} \inf_{\mathbb{P}\in\mathbf{P}} \mathbb{P}[f_{i,t} - \theta_{i+1} - \eta_{i+1} \zeta, \forall i, t,] \ge 1 - \epsilon_c, \\ f_{i,t} \le w_{i+1}(\overline{\rho}_{i+1} - \rho_{i+1,t}), \forall i, t, \end{array}\right\} \text{receive function,}$$

$$\left\{\begin{array}{l} l_{j,t+1} = l_{j,t} + (\mu_{j,t} + \delta_{j,t}\xi - r_{j,t})\Delta t, \forall j, t, \\ \inf_{\mathbb{P}\in\mathbf{P}} \mathbb{P}[l_{j,t} + (\mu_{j,t} + \delta_{j,t}\xi - r_{j,t})\Delta t \le l_{max}, \forall j, t,] \ge 1 - \epsilon_d \end{array}\right\}$$

Further Work

Analyse the COP
Construct solution algorithms
Calibrate model parameters
Apply the COP to study traffic flow – optimization problems

THANK YOU