Data fusion solution to fix the cumulative drift problem on urban arterials

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Context

Huge surge of monitoring projects in urban environments

- In the Netherlands
  - Virtually 100% vehicle actuated traffic controllers: inductive loops measuring flows (and in)
  - Last five years: huge investments in urban monitoring, particularly in AVI systems (cams, BT)
    - TRAVEL TIMES
    - REALISED ROUTES
    - PARTIAL OD RELATIONS
  - Usefulness for urban traffic management debated …

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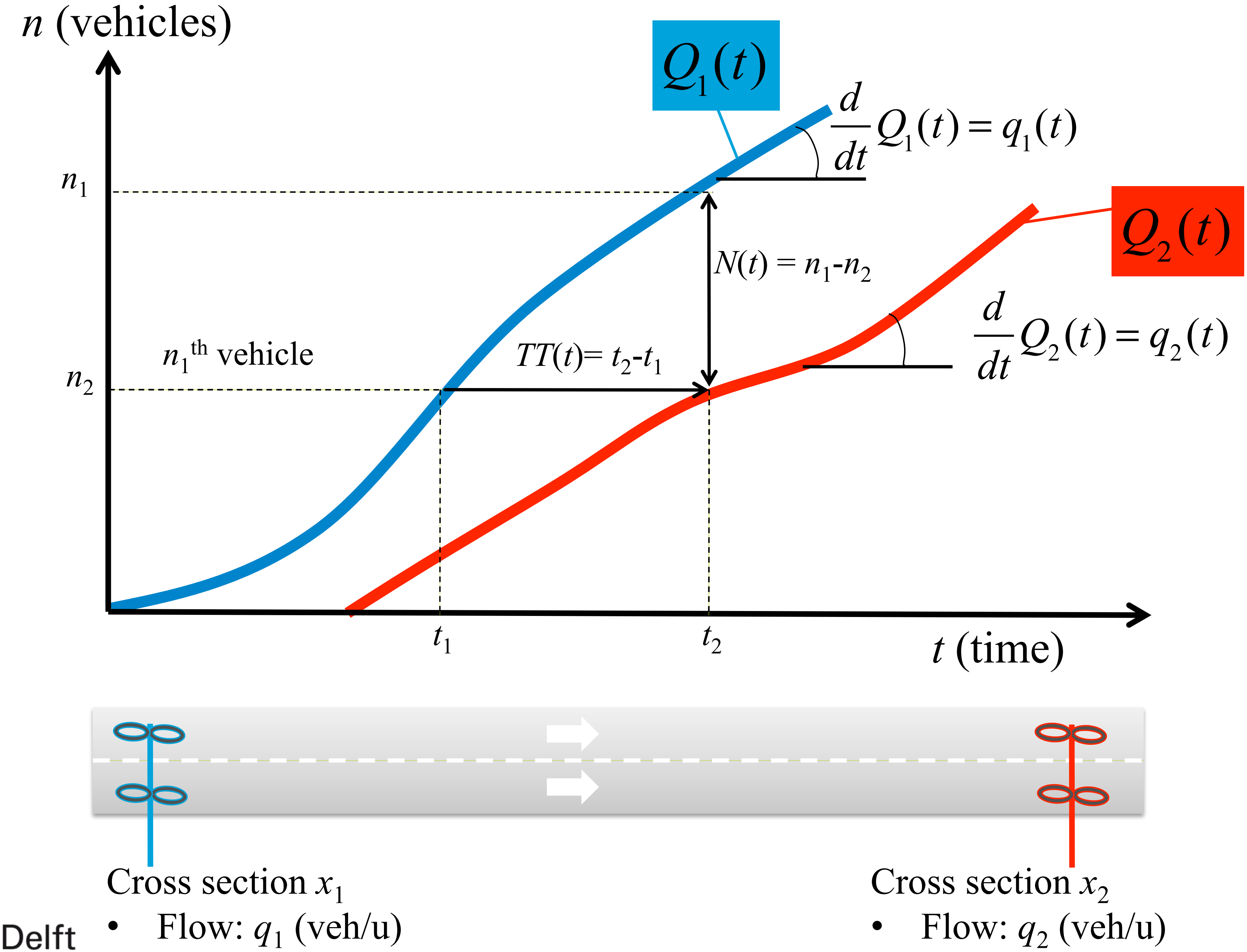
Overview

1. Deducing vehicle accumulation using vehicle counts (cum curves) is straightforward …
2. Problem: cumulative drift due to errors in counts
3. Solution: (f)use counts (with) measured travel times
4. Results of this “simple trick” are rather good



n (vehicles)
$Q_1(t)$
$\frac{d}{dt}Q_1(t) = q_1(t)$
n_1
$Q_2(t)$
$N(t) = n_1 - n_2$
$\frac{d}{dt}Q_2(t) = q_2(t)$
n_1^{th} vehicle
$TT(t) = t_2 - t_1$
n_2
t_1
t_2
t (time)
Cross section x_1
• Flow: q_1 (veh/u)
Cross section x_2
• Flow: q_2 (veh/u)

The cumulative drift problem

Occurs when $q_1(t)$ and $q_2(t)$ contain errors

- Source errors (miscounts, double counts):
  - lane changes, power failure, etc.

- Errors may be random or structural (bias)
- Consequence:

$$N(t) = \int_t q_1(s)\,ds - \int_t q_2(s)\,ds$$

$$q_i(t) = \hat{q}_i(t) + \varepsilon_i(t)$$

With e.g. $\varepsilon_i(t) \sim \mathcal{N}(\mu, \sigma)$

The cumulative drift problem

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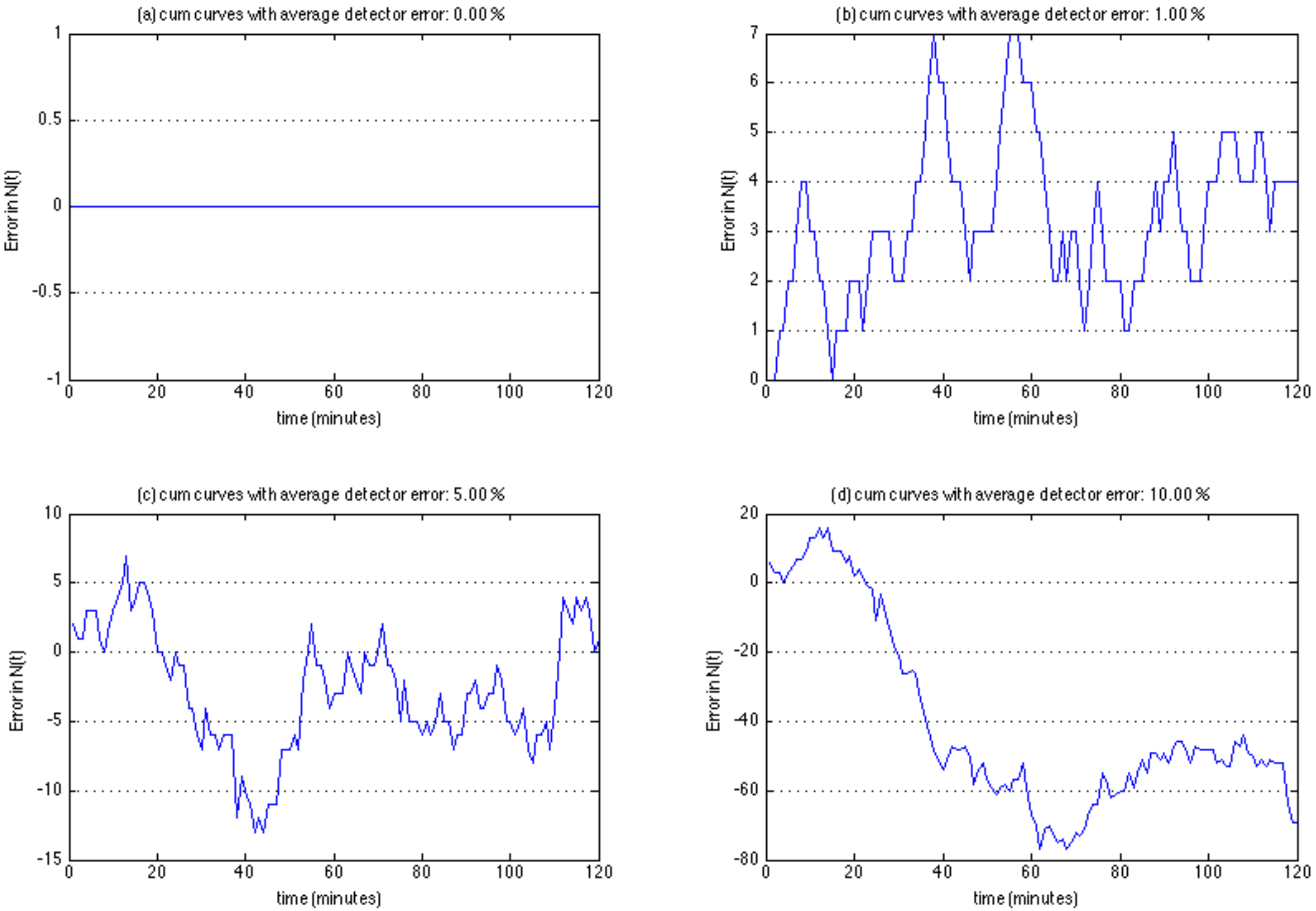
- Consequence:

$$\left.\begin{array}{c} N(t) = \int_t q_1(s)\,ds - \int_t q_2(s)\,ds \\ q_i(t) = \hat{q}_i(t) + \varepsilon_i(t) \end{array}\right\} N(t) = \hat{N}(t) + \int_t \big(\varepsilon_1(s) - \varepsilon_2(s)\big)\,ds$$

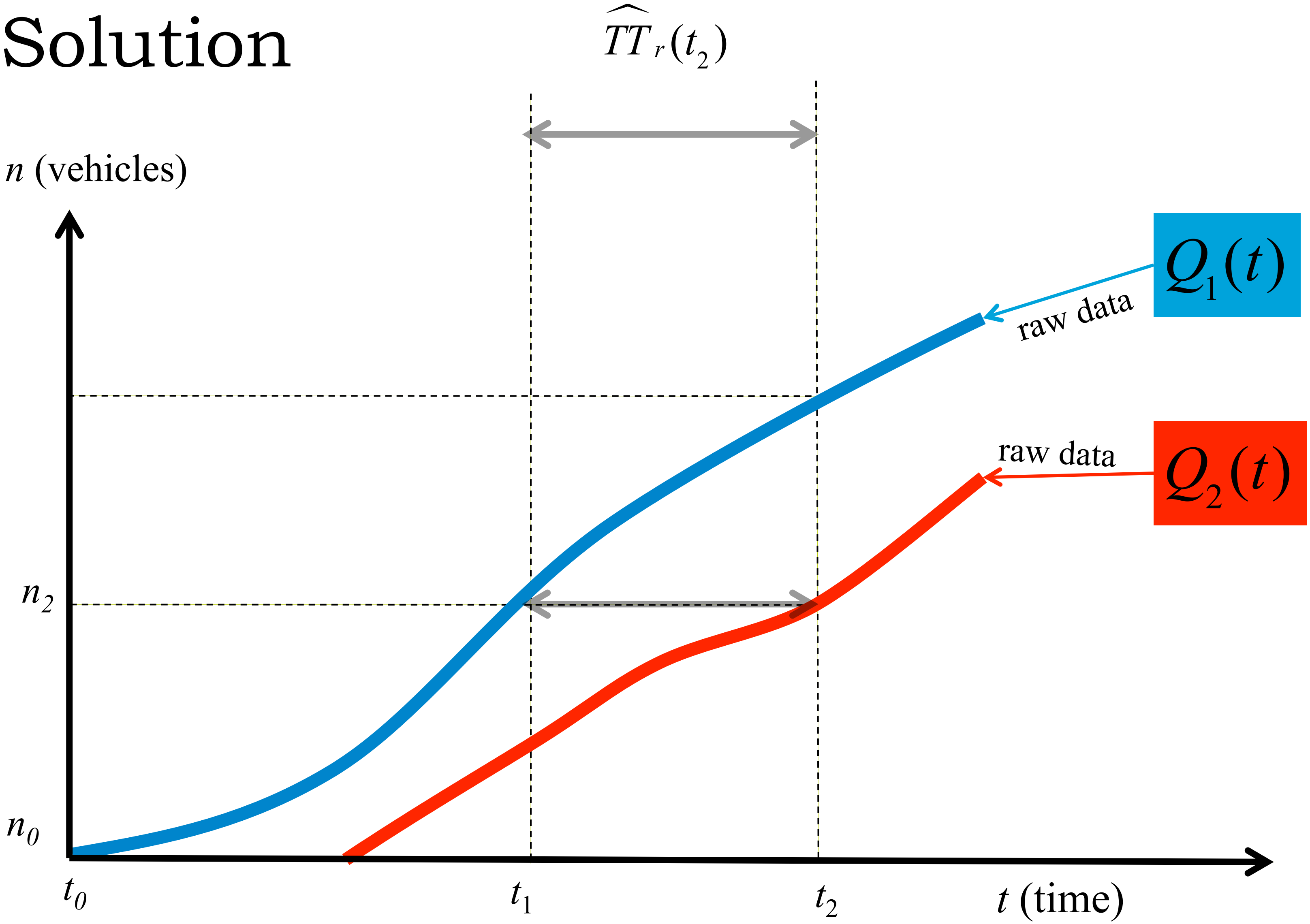
This is a random walk!

(which means vehicle accumulation is practically unobservable using counts)

The cumulative drift problem

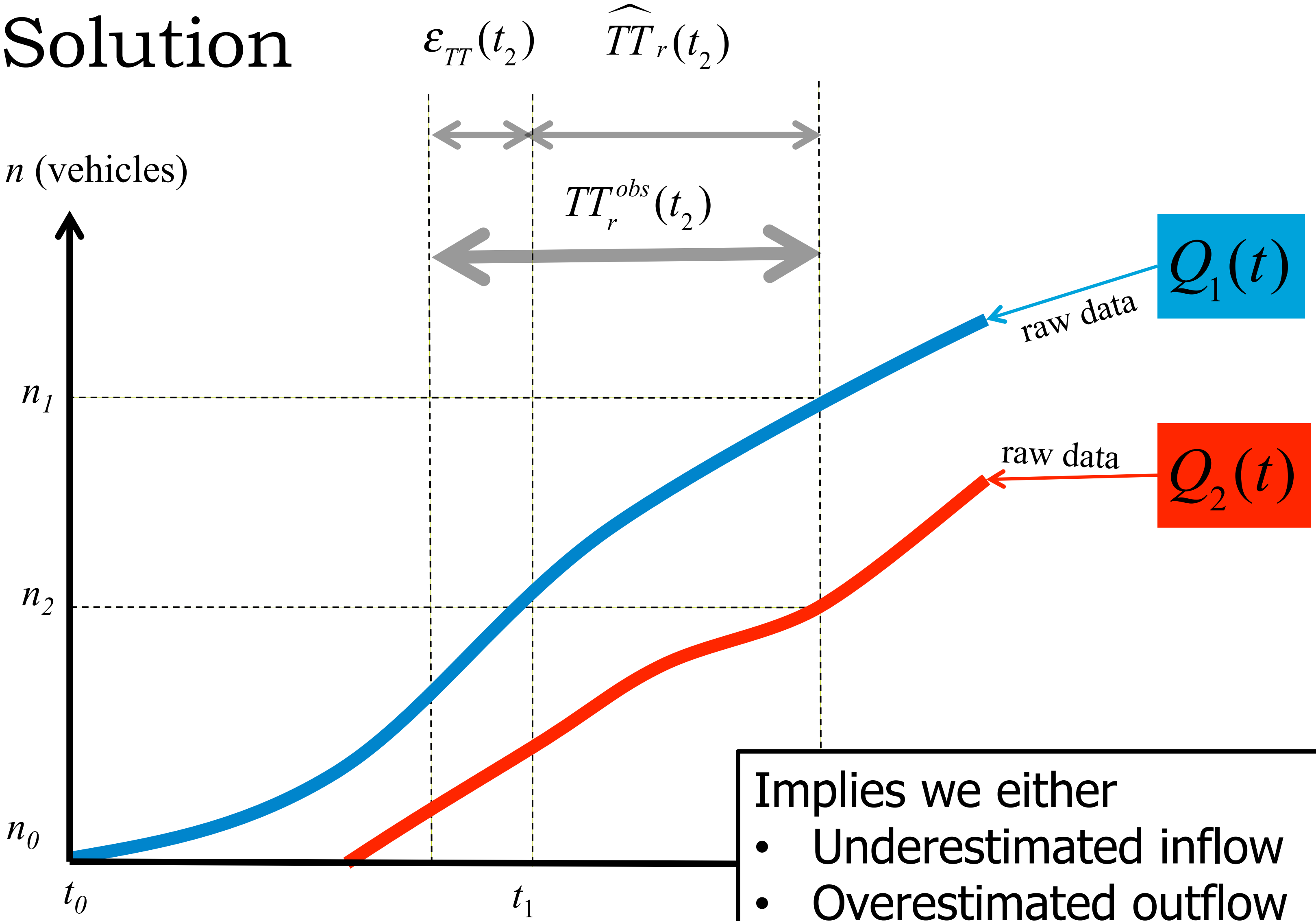


Solution



$\widehat{TT}_r(t_2)$
n (vehicles)
$Q_1(t)$
raw data
raw data
$Q_2(t)$
n_2
n_0
t_0
t_1
t_2
t (time)

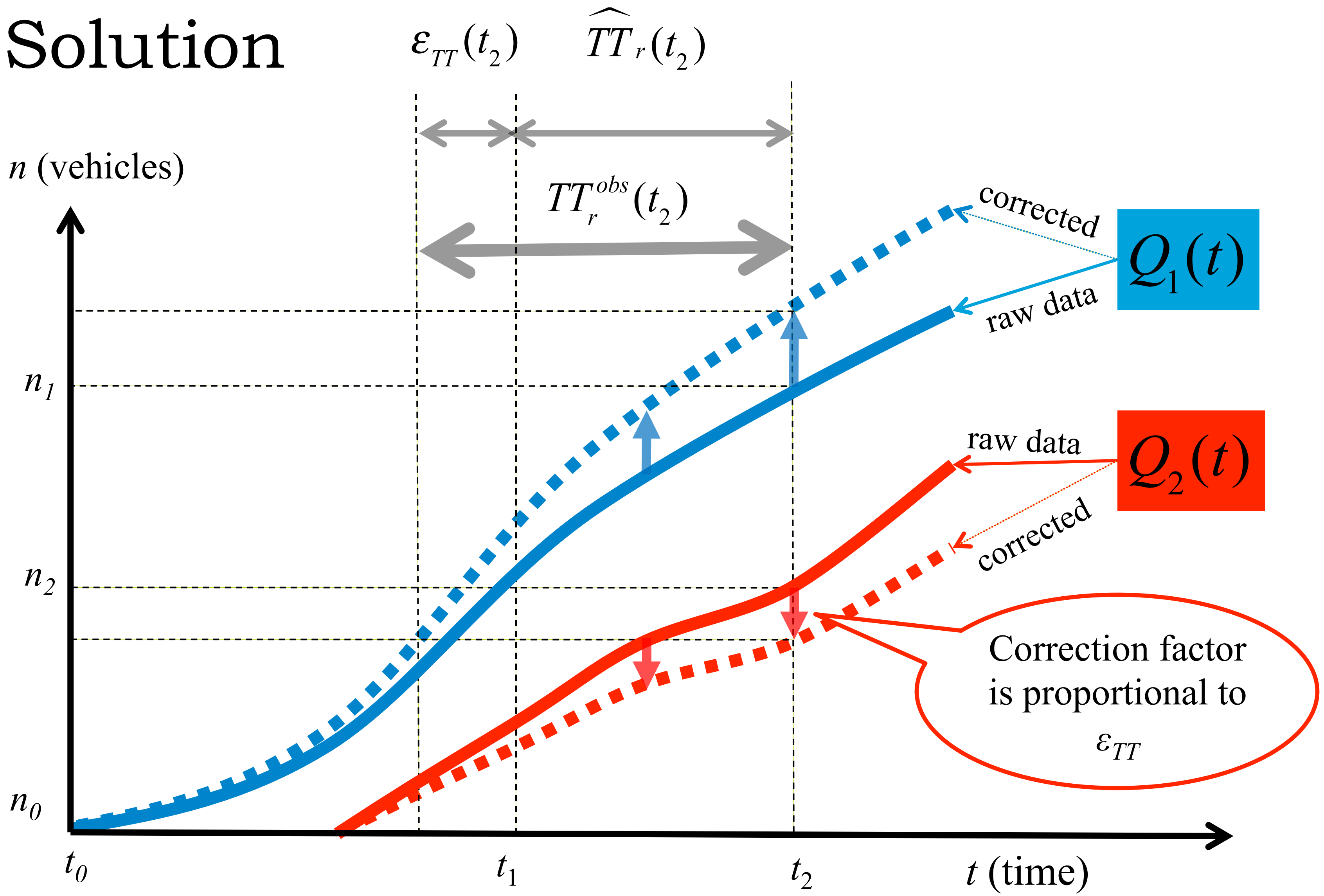
Solution



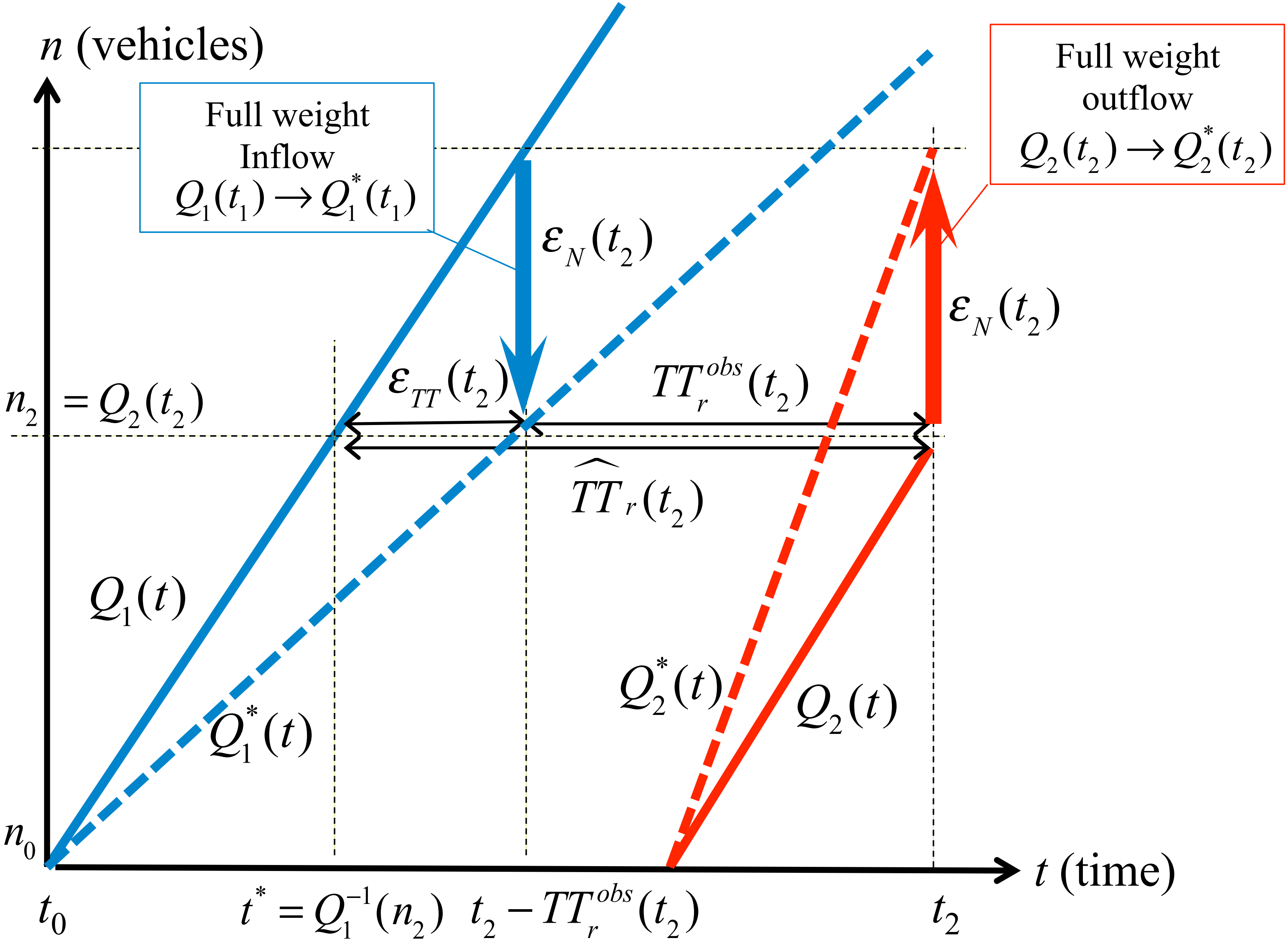
Implies we either

- Underestimated inflow
- Overestimated outflow
- Or both

Solution



$\varepsilon_{TT}(t_2)$
$\widehat{TT}_r(t_2)$
n (vehicles)
$TT_r^{obs}(t_2)$
corrected
$Q_1(t)$
raw data
n_1
raw data
$Q_2(t)$
corrected
n_2
Correction factor is proportional to ε_{TT}
n_0
t_0
t_1
t_2
t (time)


n (vehicles)
Full weight Inflow $Q_1(t_1) \rightarrow Q_1^*(t_1)$
Full weight outflow $Q_2(t_2) \rightarrow Q_2^*(t_2)$
$\varepsilon_N(t_2)$
$\varepsilon_N(t_2)$
$\varepsilon_{TT}(t_2)$
$TT_r^{obs}(t_2)$
$\widehat{TT}_r(t_2)$
$n_2 = Q_2(t_2)$
$Q_1(t)$
$Q_1^*(t)$
$Q_2^*(t)$
$Q_2(t)$
n_0
t_0
$t^* = Q_1^{-1}(n_2)$
$t_2 - TT_r^{obs}(t_2)$
t_2
t (time)

Solution turns out to be

A simple parameter-free correction algorithm

- Correction factor can be expressed as function of known quantities only

$$\frac{\varepsilon_N(t_2)}{\varepsilon_{TT}(t_2)} = \frac{n_2 - n_0}{t^* - t_0}$$

- Or more generally

$$\varepsilon_N(t_i) = \varepsilon_{TT}(t_i)\frac{Q_i(t_i) - n_0}{Q_{i-1}^{-1}(n_i) - Q_{i-1}^{-1}(n_0)}$$

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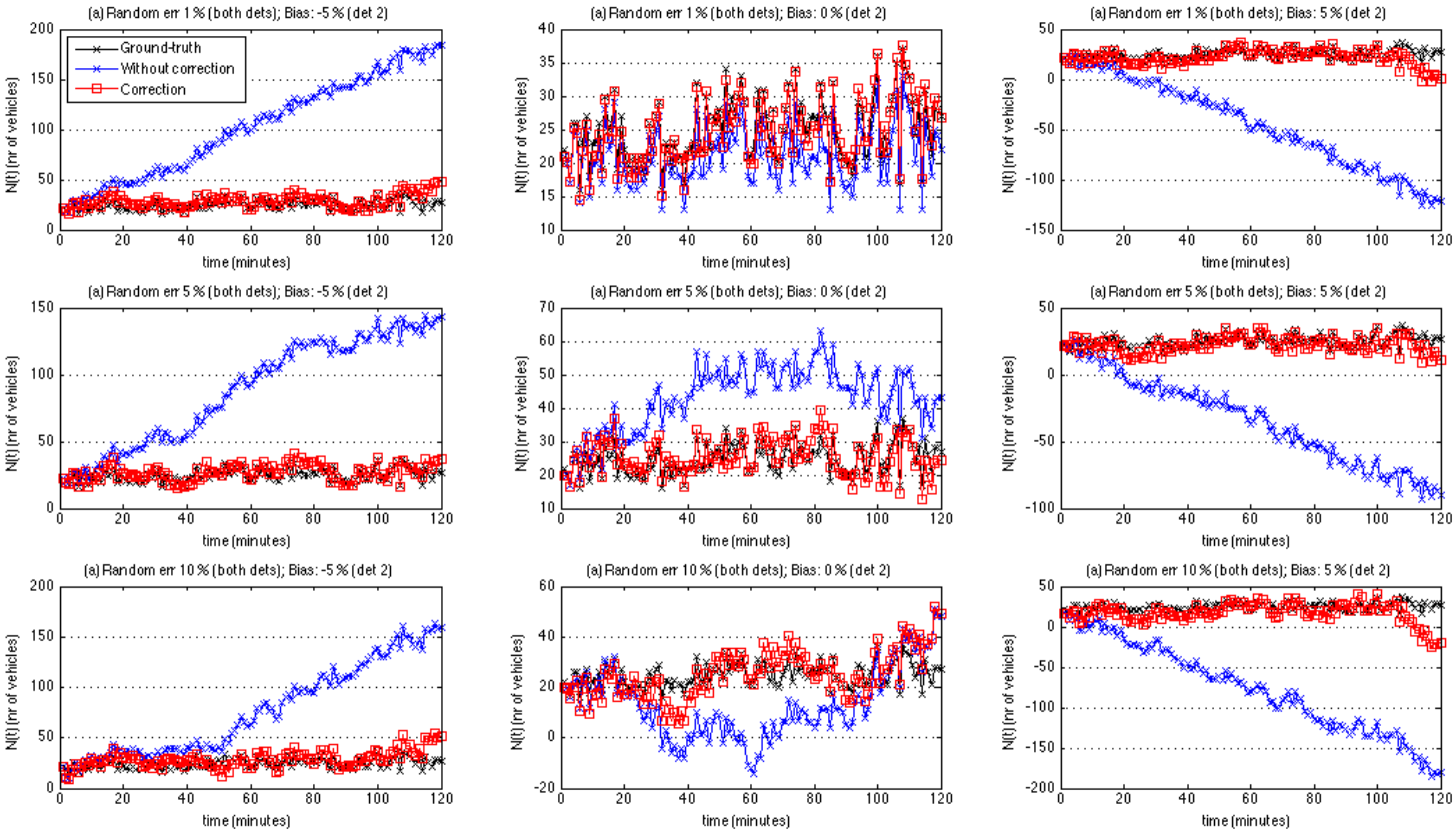
Results

Rows (random errors): {1%, 5%, 10%}
Columns (bias): {-5%, 0, 5%};



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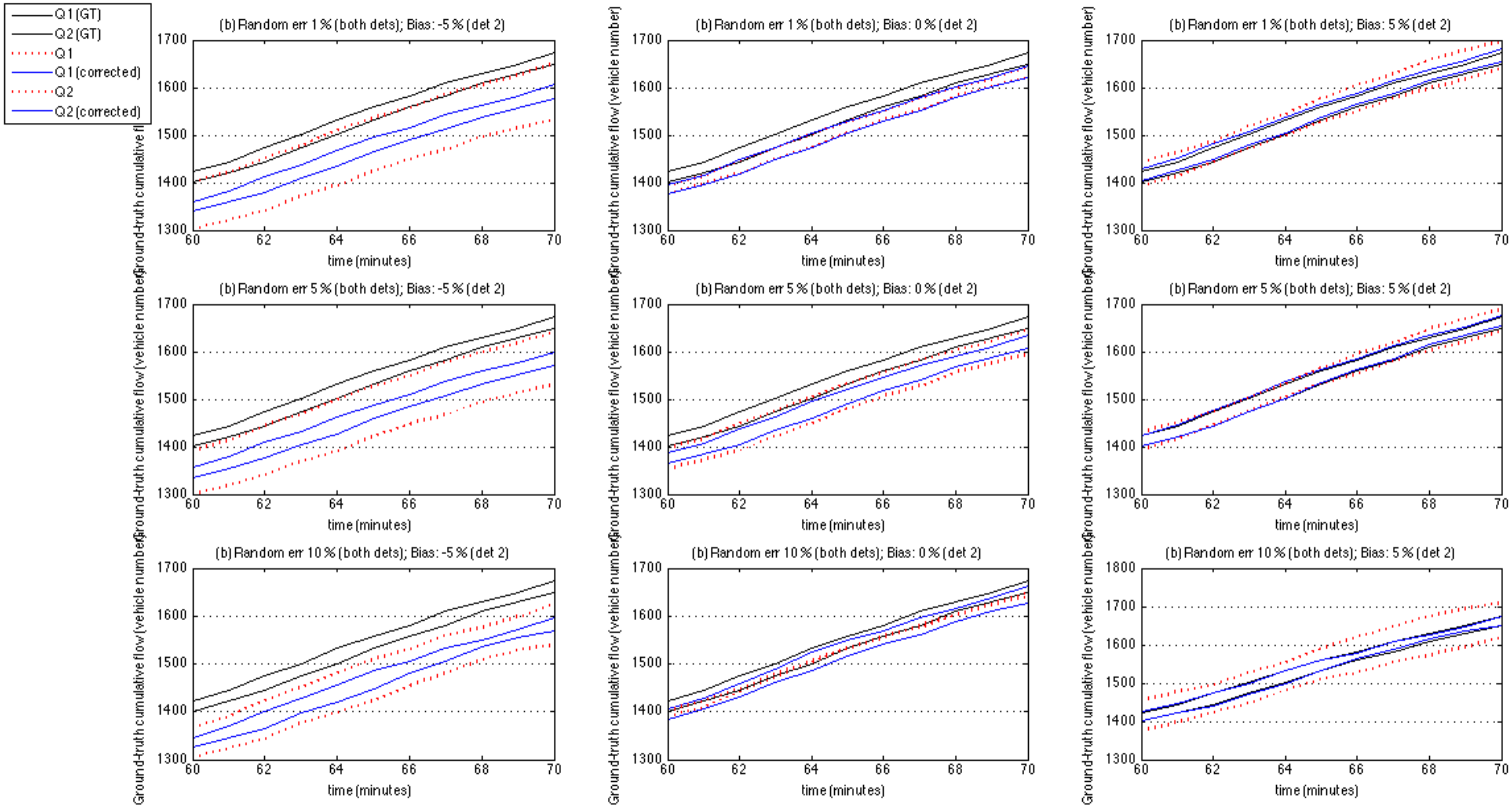

Discussion

- Good news for urban traffic management agencies:
  - Algorithm works offline or online (although with a time lag of course)
- Quite a few puzzles to solve:
  - Limits algorithm (magnitude and nature of errors)
  - What to do when no closed counting situation?
  - What to do when no measured travel times?
  - How to incorporate travel time errors?

Next steps …

- Solve puzzles
- Pubs:
  - TRB2015 paper:
    - Basic idea + extension to multiple links
  - TFT50 / special issue jnl paper
    - Basics TRB Paper
    - + combination with additional methods
    - + real data case studies