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 ...
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)

Cross section $x_1$
- Flow: $q_1$ (veh/u)

Cross section $x_2$
- Flow: $q_2$ (veh/u)

$Q_1(t) = \frac{d}{dt} Q_1(t) = q_1(t)$

$Q_2(t) = \frac{d}{dt} Q_2(t) = q_2(t)$

$N(t) = n_1 - n_2$

$TT(t) = t_2 - t_1$

$n_1^{th}$ vehicle
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:

$$N(t) = \int_{t}^{s} q_1(s) \, ds - \int_{t}^{s} q_2(s) \, ds$$

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

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

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:

\[
\begin{align*}
N(t) &= \int_{t}^{\hat{N}(t)} q_1(s) \, ds - \int_{t}^{\hat{N}(t)} q_2(s) \, ds \\
q_i(t) &= \hat{q}_i(t) + \varepsilon_i(t)
\end{align*}
\]

\[
N(t) = \hat{N}(t) + \int_{t}^{\hat{N}(t)} \left( \varepsilon_1(s) - \varepsilon_2(s) \right) \, ds
\]

This is a random walk!

(which means vehicle accumulation is practically unobservable using counts)
The cumulative drift problem

(a) Cum curves with average detector error: 0.00 %

(b) Cum curves with average detector error: 1.00 %

(c) Cum curves with average detector error: 5.00 %

(d) Cum curves with average detector error: 10.00 %
Solution

\[ n \text{ (vehicles)} \]

\[ \widehat{TT}_r(t_2) \]

\[ Q_1(t) \]

\[ Q_2(t) \]

raw data

\[ n_0 \]

\[ n_2 \]

\[ t_0 \]

\[ t_1 \]

\[ t_2 \]

\[ t \text{ (time)} \]
Solution

\[ n(t) = Q_1(t) \cap Q_2(t) \]

\[ \varepsilon_{TT}(t_2) \quad \widehat{TT}_r(t_2) \]

\[ TT_{r,obs}(t_2) \]

\[ T_T^r(t_2) \]

Implies we either
- Underestimated inflow
- Overestimated outflow
- Or both
Solution

\[ \varepsilon_{TT}(t_2) \quad \widehat{TT}_r(t_2) \]

\[ n (\text{vehicles}) \]

\[ n_1 \quad n_2 \quad n_0 \]

\[ t_0 \quad t_1 \quad t_2 \quad t \text{ (time)} \]

Correction factor is proportional to \( \varepsilon_{TT} \)

\[ Q_1(t) \quad Q_2(t) \]

Corrected

Raw data
\[ n_0 = Q_1(t_1) \rightarrow Q_1^*(t_1) \]

\[ n_2 = Q_2(t_2) \]

\[ t^* = Q_1^{-1}(n_2) \]

\[ t_2 = TT_r^{obs}(t_2) \]

\[ t_2 = TT_r(t_2) \]

\[ Q_1^*(t_1) \rightarrow Q_2(t_2) \]

\[ Q_1(t) \]

\[ Q_2(t) \]

\[ Q_2^*(t) \]

\[ TT_r^{obs}(t_2) \]

\[ TT_r(t_2) \]
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

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

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

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