A State-Space Model For Assimilating Passenger And Vehicle Flow Data With User Feedback In A Transit Network

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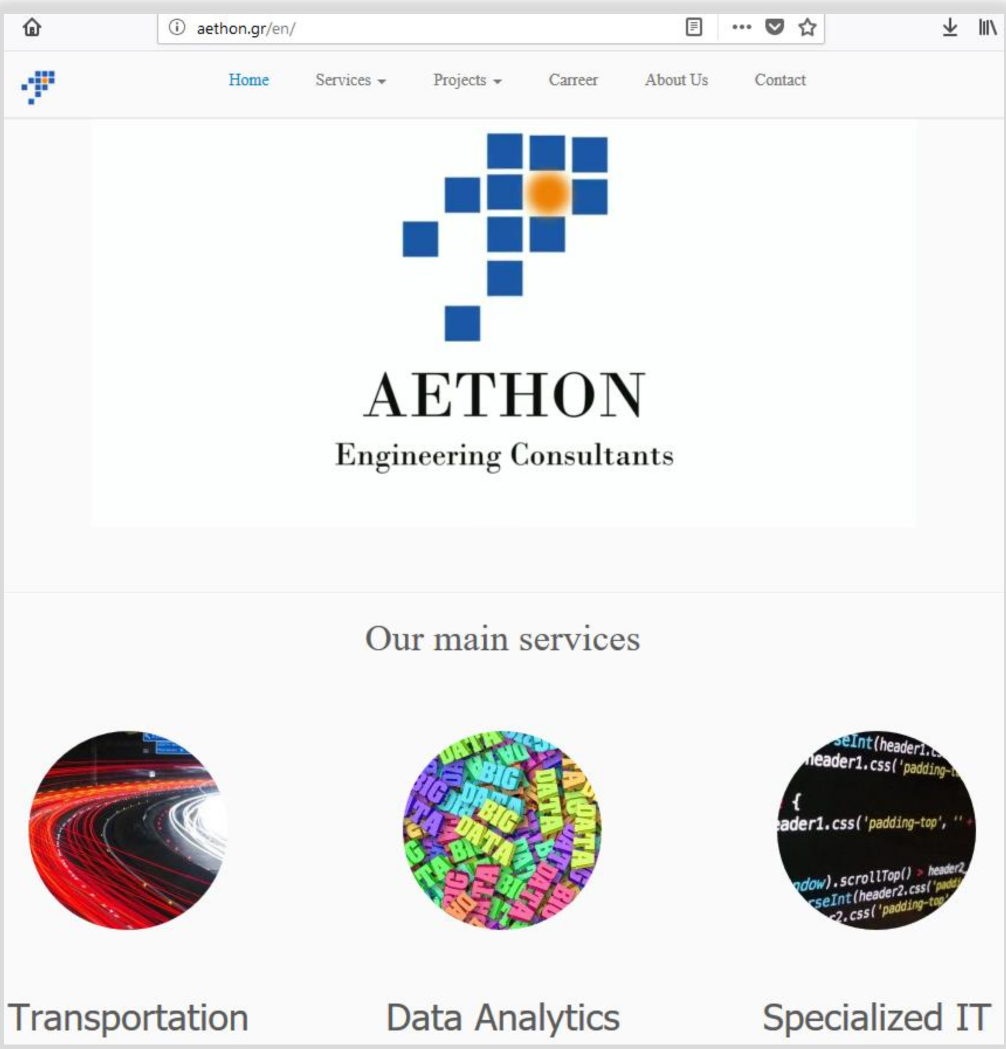
Engineering Consultants

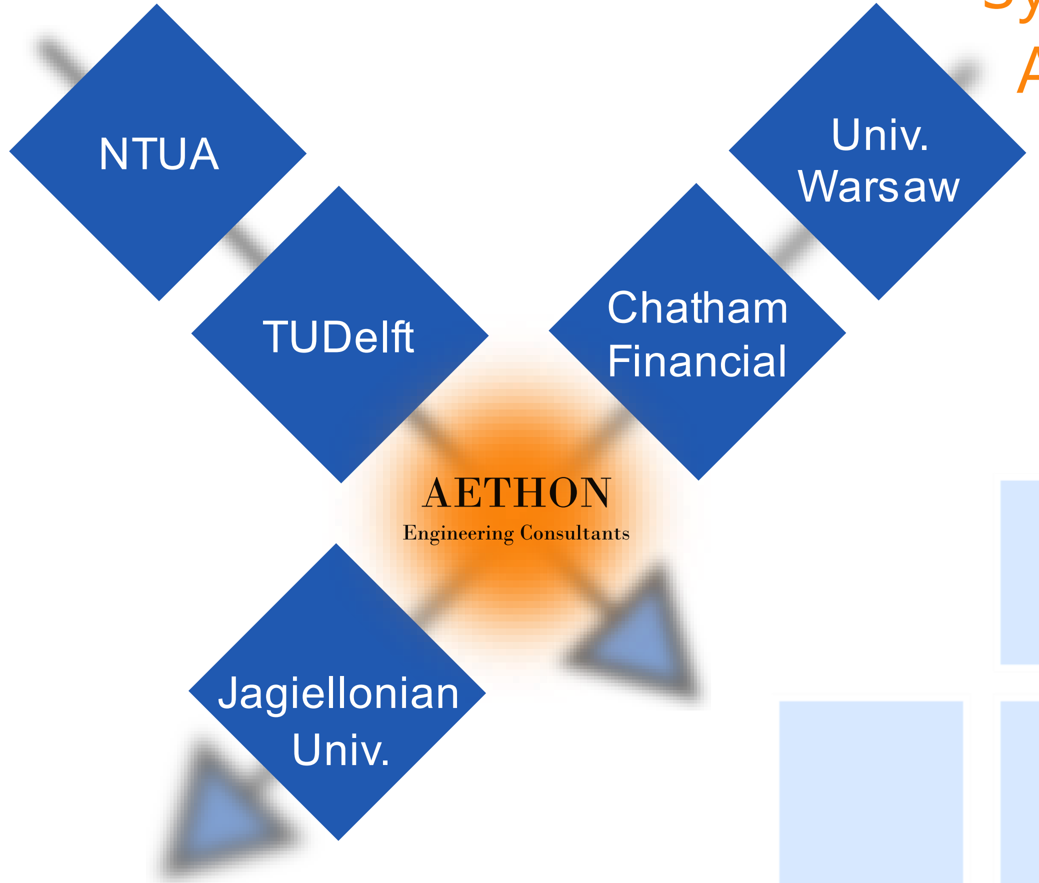
MATTS 2018, TUDelft, October 2018

MoveWise
prototype

Alexandros Papacharalampous

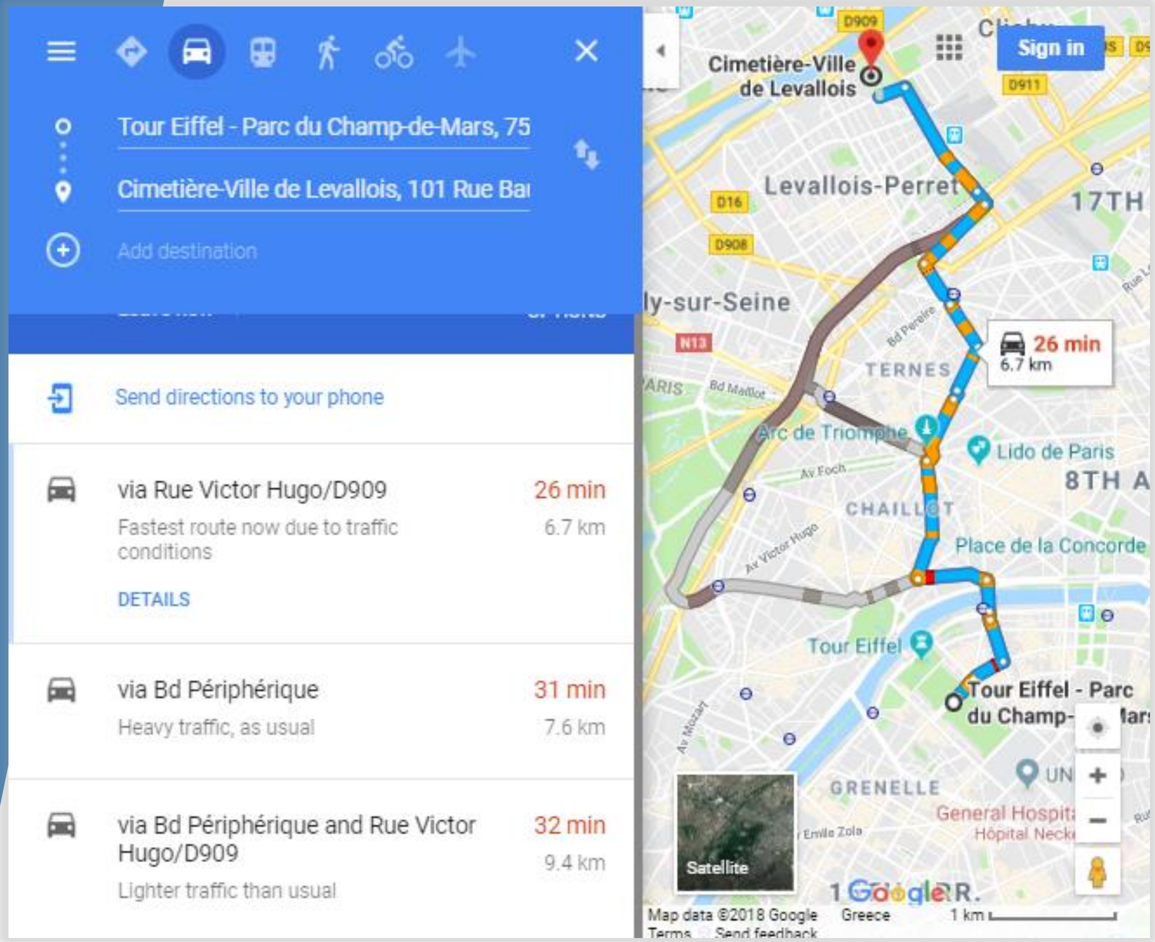


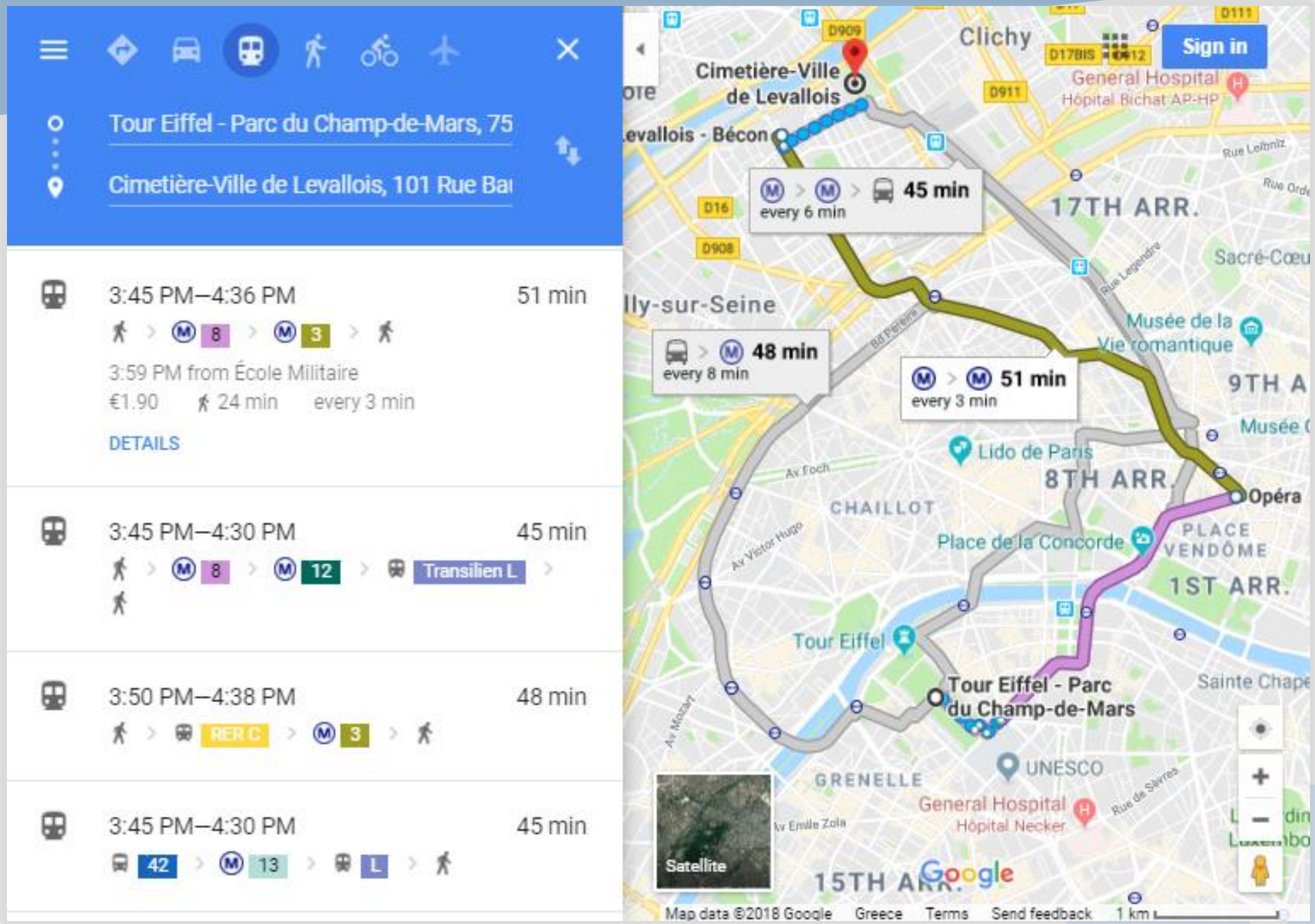
Sylwester Arabas



MoveWise prototype

idea!





solution?

MoveWise prototype

Why one would care about crowdedness?

see e.g. “Crowding in public transport: Who cares and why?”: Haywood et al. 2017

- ability to seat/work/board (uncertainty)
- safety, security, hygiene, thermal comfort (stress)
- infrastructure/resource use (inefficiencies)

How and what for to use information on crowdedness?

see e.g. “A Mesoscopic Transit Assignment Model Including Real-Time Predictive Information on Crowding”: Nuzzolo et al. 2016,
“Simulating the effects of real-time crowding information in public transport networks”: Drabicki et al. 2017,
“Impact of real-time crowding information: a Stockholm metro pilot study“: Zhang et al. 2017

- route planning (route/mode choice)
- real-time information provision (load optimisation)
- planning … (operator’s perspective)

What data could one use (assimilate)?

- vehicle positions
- schedules / headway times
- vehicle weighing (e.g., Nielsen et al. 2014, Jenelius 2018)
- station gate entry/exit counts
- smartcard data
- automatic passenger counters (APCs) (e.g., Pinna & Dalla Chiara 2010)
- image recognition (e.g., Toyosawa & Kawai 2005)
- comm. device counting - WiFi/GSM (e.g., Schauer et al 2014)
- user feedback (e.g., Moovit)

simple state-space model?

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$
$$z_k = H x_k + v_k$$

minimal test-case dataset?

prototype implementation?

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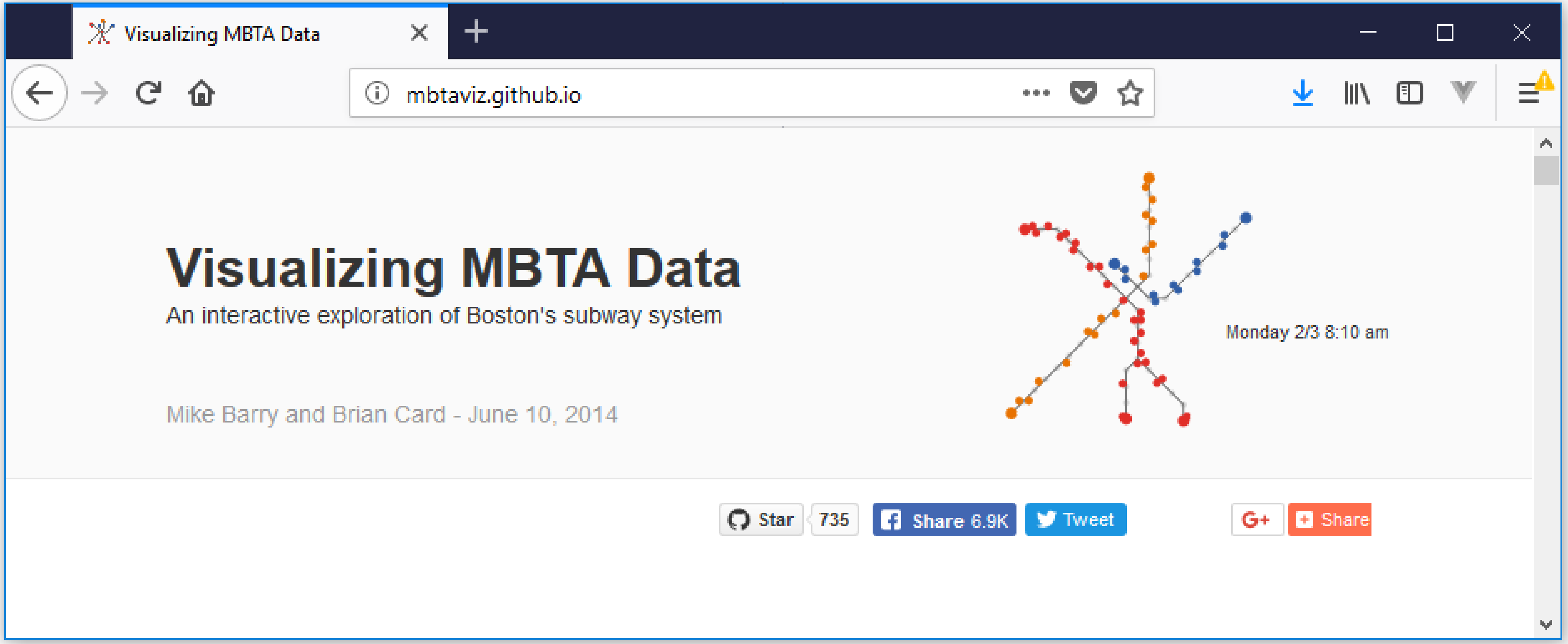


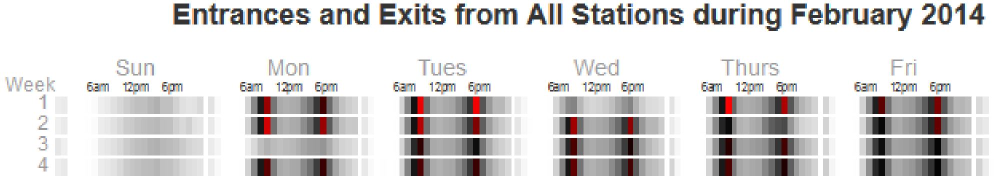
Accompanied by an open dataset released by Boston’s Massachusetts Bay Transit Authority (MBTA):

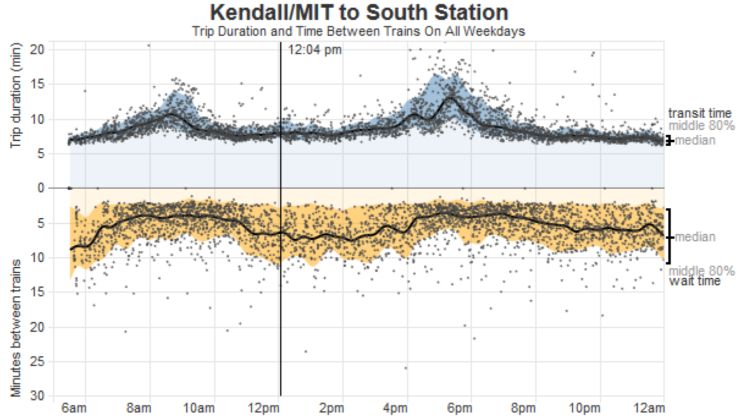
- 3 subway lines, 4 weeks of data
- turnstile counts with 1-min. time resolution
- train position data
- archive of alerts

MoveWise prototype

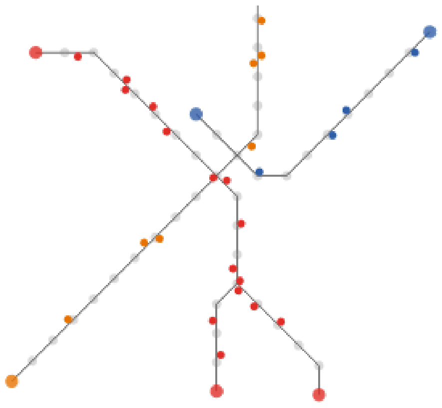
mbtaviz.github.io

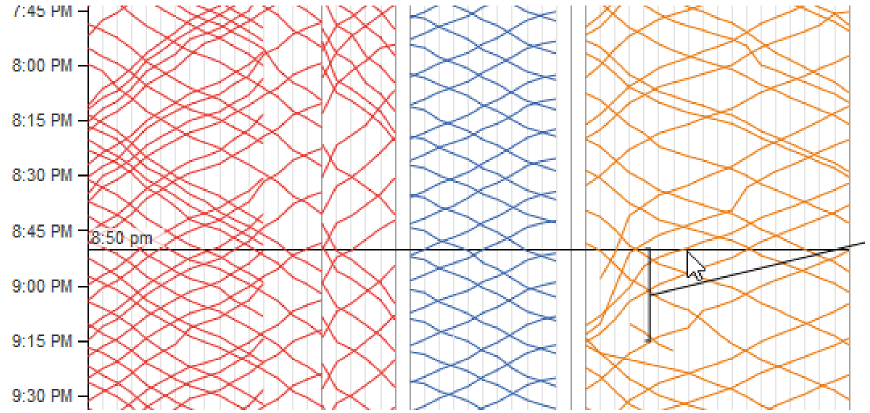
Barry & Card, 2014





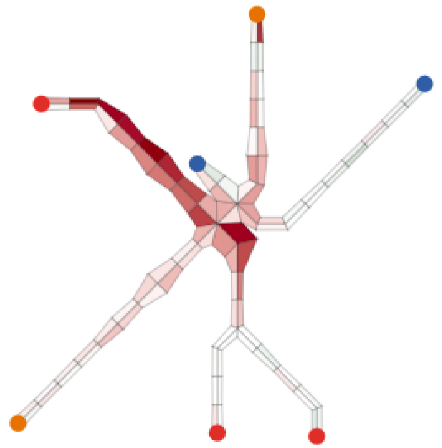
At 12:04 pm trains leave every 3 to 11 minutes from Kendall/MIT going to South Station. The trip takes between 7 and 10 minutes. The shortest time from when you walk into Kendall/MIT until you walk out of South Station is 7 minutes but it can be as long as 21 minutes. Usually it takes about 11 minutes including wait and transit time.



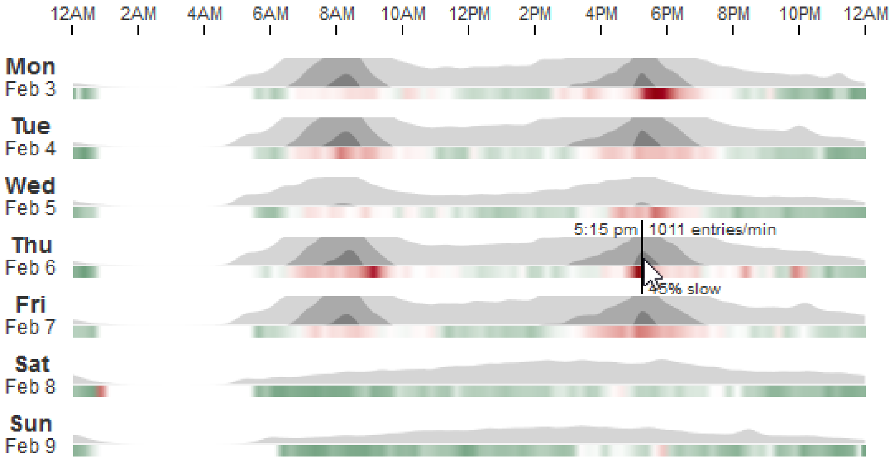


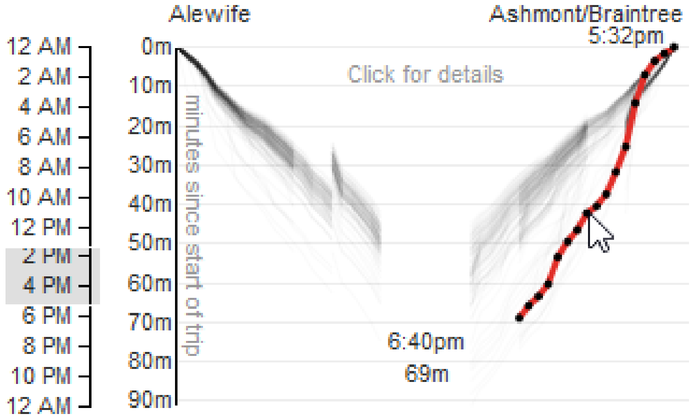
A disabled train at Wellington Station causes northbound delays on the Orange Line from 8:50PM to 9:15PM

Notice how southbound trains are temporarily delayed, but get back on schedule quickly.



5:15 pm on Thu Feb 6





simplest state-space model?

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$
$$z_k = H x_k + v_k$$

minimal test-case dataset?

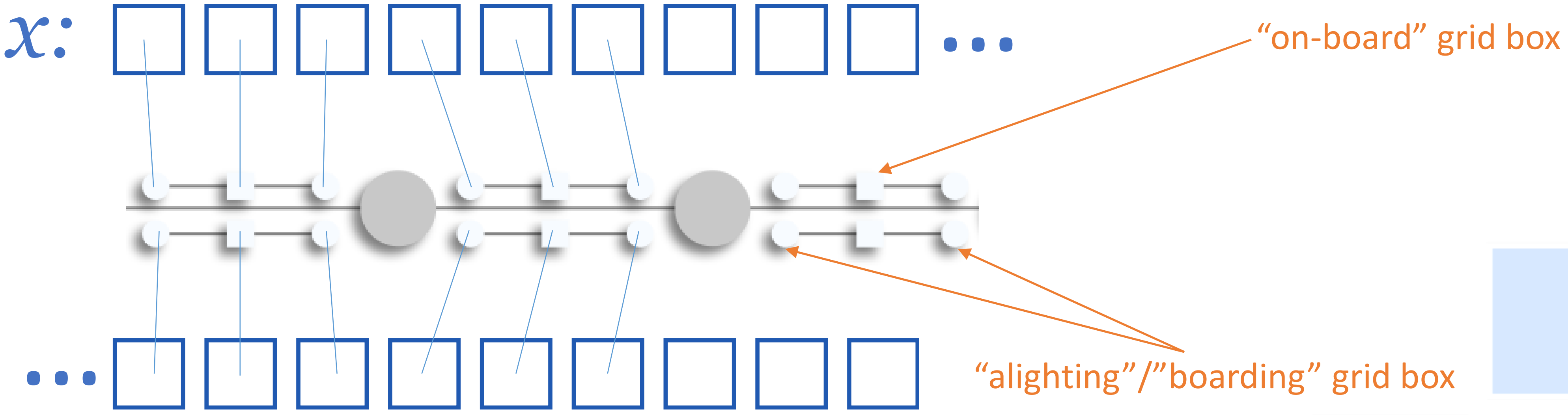
prototype implementation?

state vector x

(k: time level)

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$

$$z_k = H x_k + v_k$$



$$x_k = F_k x_{k-1} + B_k u_k + w_k$$
$$z_k = H x_k + v_k$$

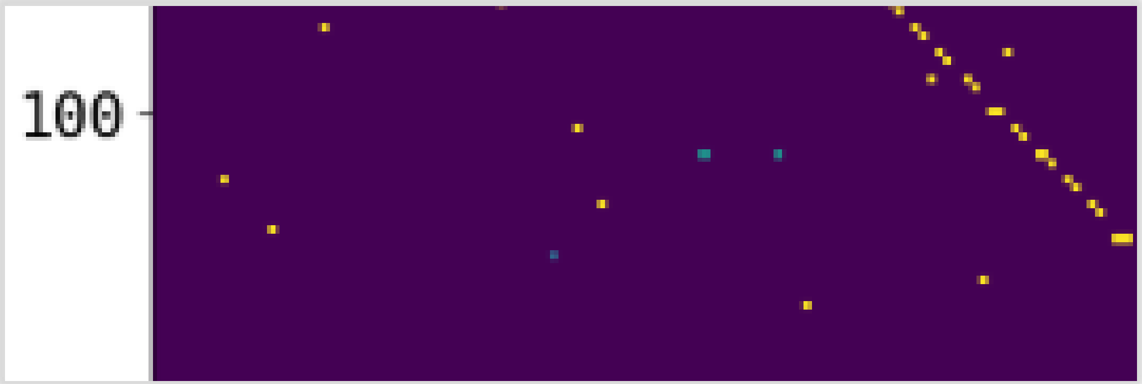
state transition matrix F
(k: time level)

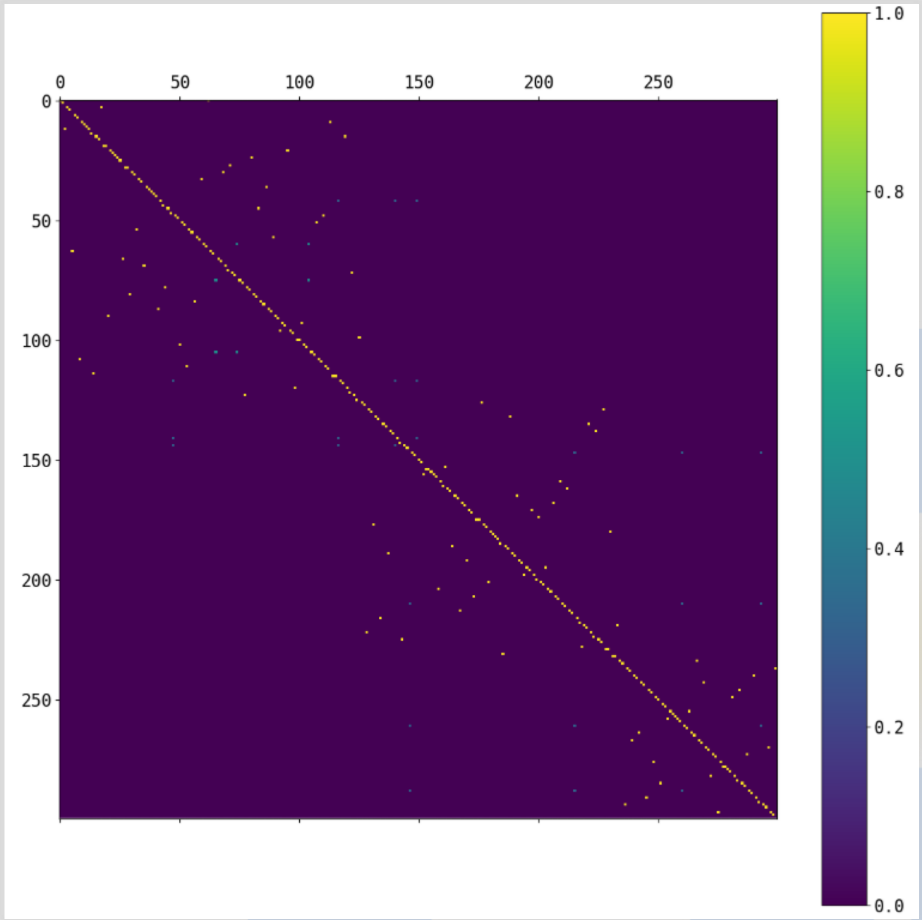
single-line case:

F: Boolean bidiagonal time-dependent matrix

multi-line network:

F includes probabilities of transfer
(rationale for alighting/boarding grid boxes)





control vector u

(k: time level)

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$

$$z_k = H x_k + v_k$$


http://www.tornosnews.gr/en/transport/

https://www.cleverdevices.com

$$n_u \neq n_x$$

NB: interplay between $\boldsymbol{Fx}$ and $\boldsymbol{Bu}$ makes the model capable of:

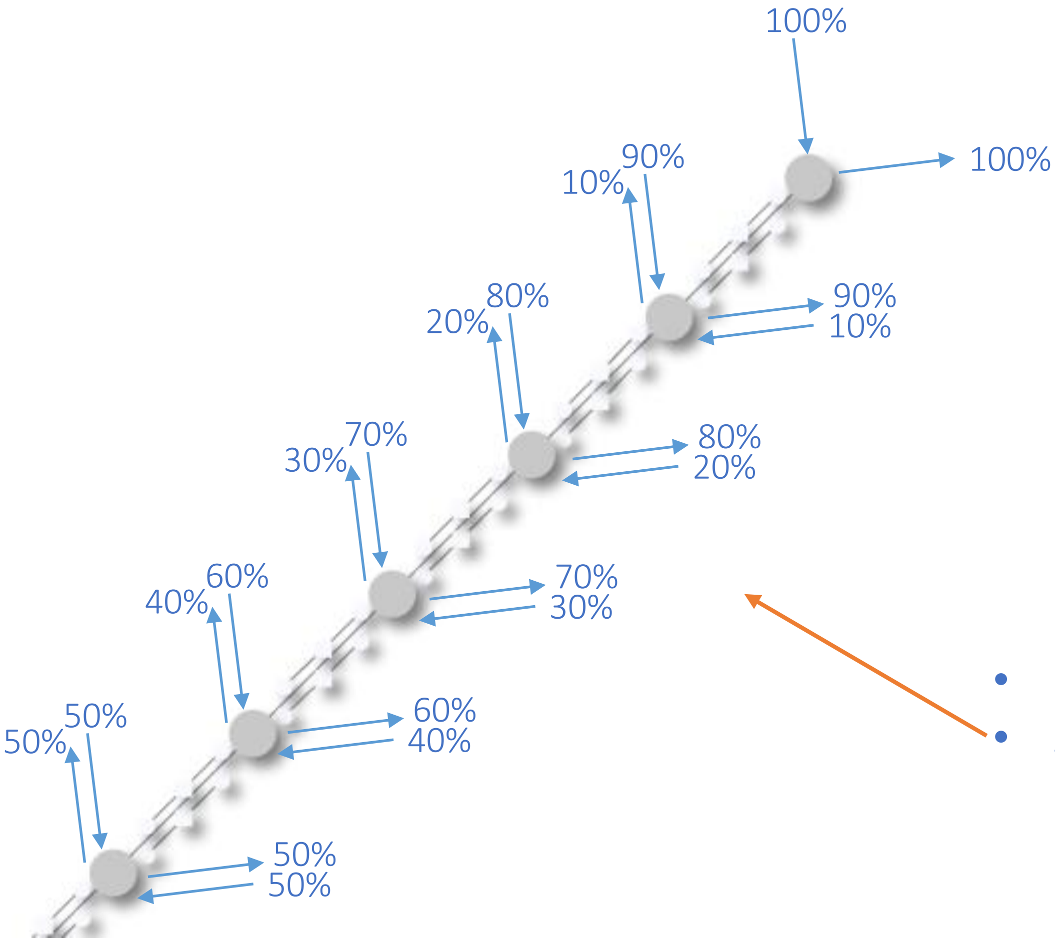
- representing accumulation of waiting passengers on platforms
- coping with (slightly) unsynced passenger/vehicle data

control transition matrix $\boldsymbol{B}$

(k: time level)

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$

$$z_k = H x_k + v_k$$



NB: conservation of total passenger count (constraint on $\boldsymbol{B}$ and $\boldsymbol{F}$):

$$\Sigma u_k + \Sigma x_{k-1} = \Sigma x_k$$

- OD matrix-based?
- simpler: constant B?

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$

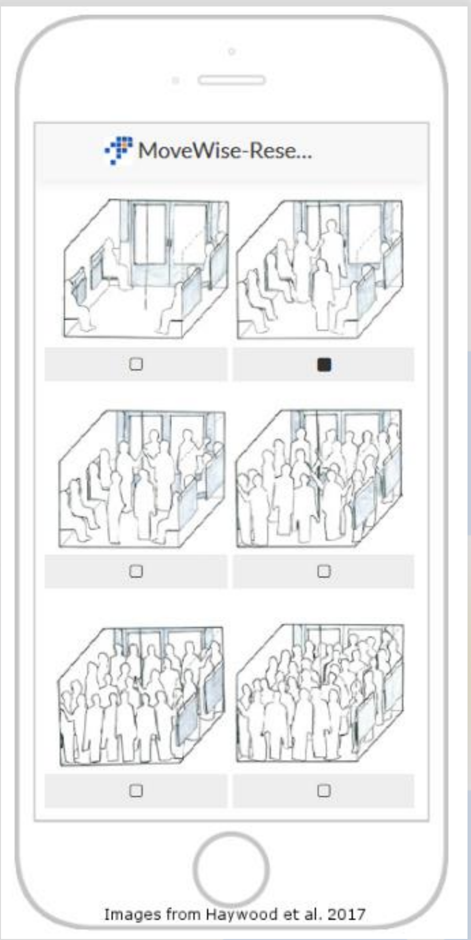
measurement vector z
observation matrix H

$$z_k = H x_k + v_k$$

- unlike the $\boldsymbol{Bu}$ term, $\boldsymbol{z}$ and $\boldsymbol{H}$ are applicable to integral measurements (differential data corresponding to entry/exit counts)
- $\boldsymbol{H}$ allows to express spatial granularity assumptions
- not limited to one measurement type!

images.foxnews.com

Pinna & Dalla Chiara 2010



Images from Haywood et al. 2017

MoveWise prototype

Gaussian noise terms w, v

(k: time level)

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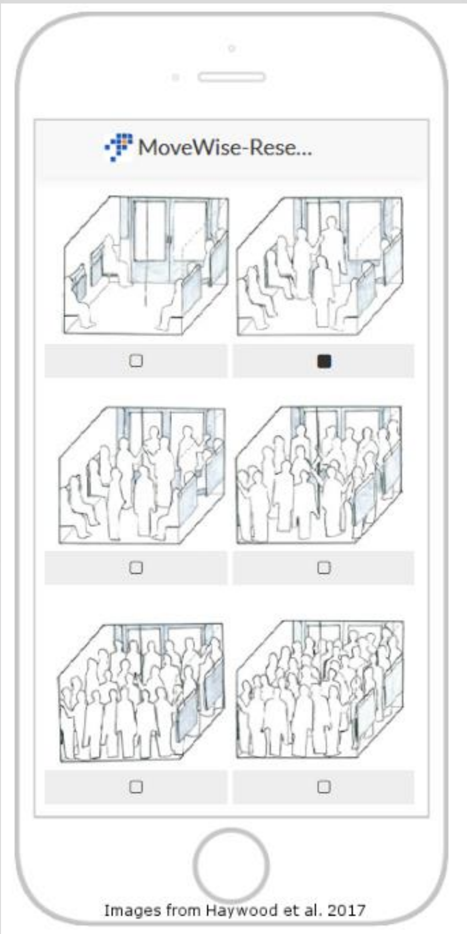

- sources of uncertainty: model & measurement
- prospect for applying Kalman filtering
  (then, different uncertainties for different measurement types)

simple state-space model?

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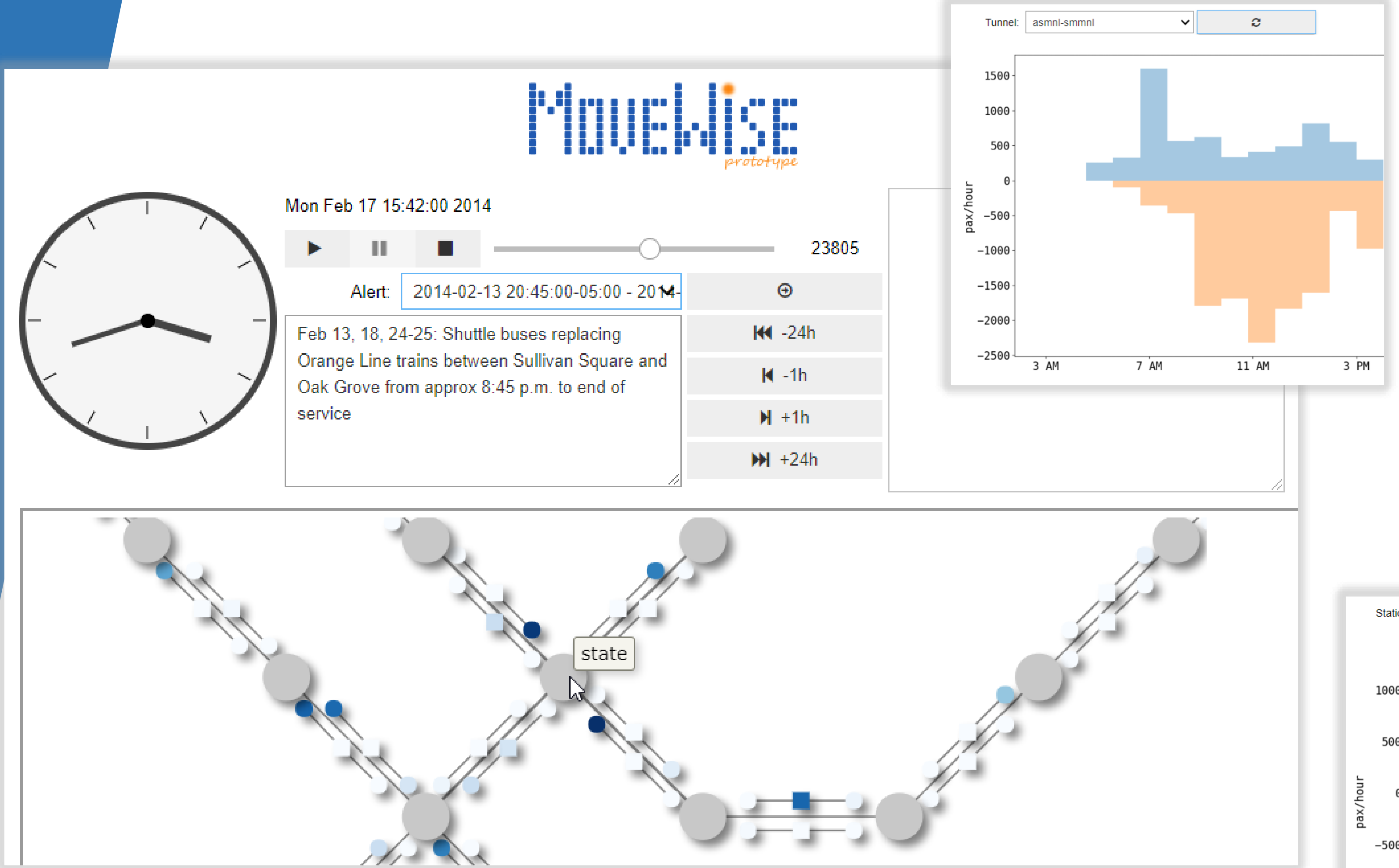
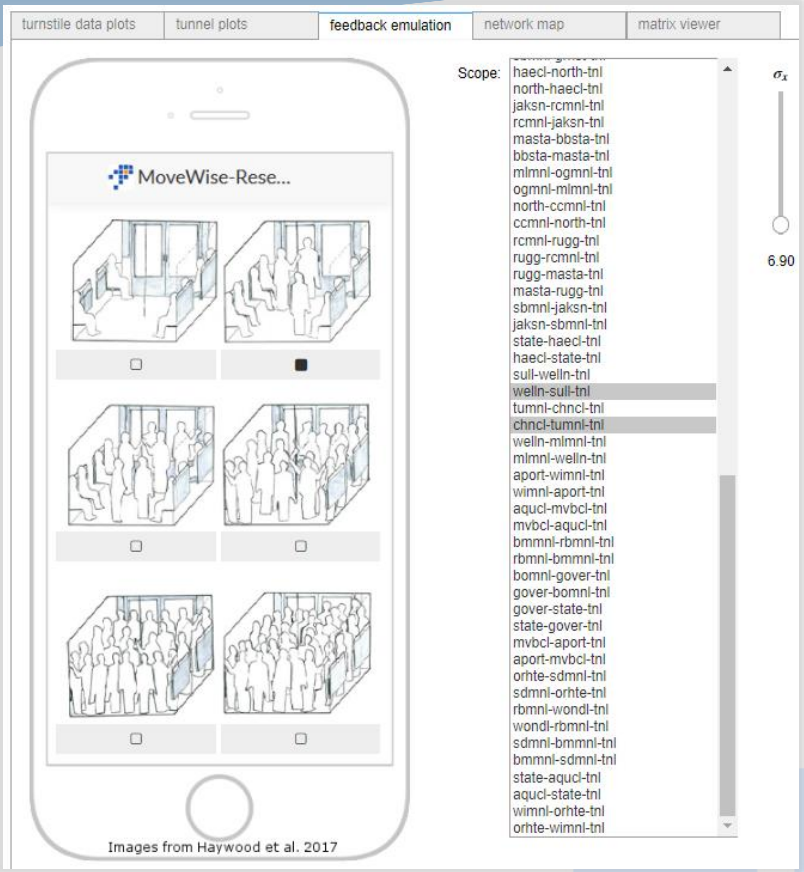
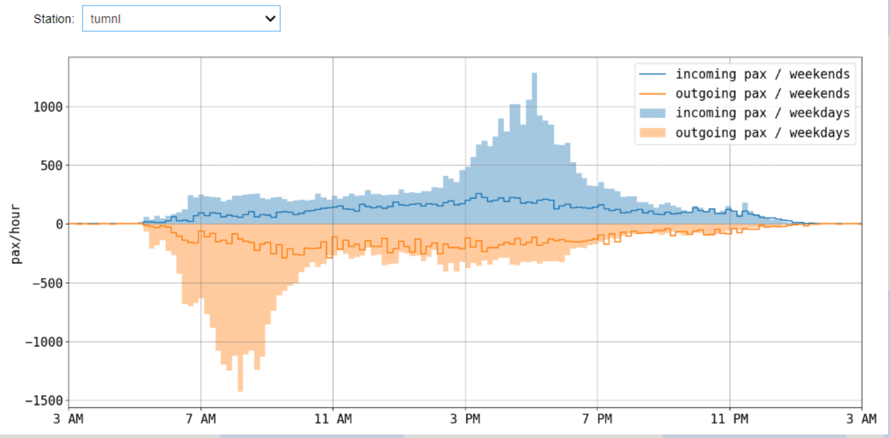
minimal test-case dataset?

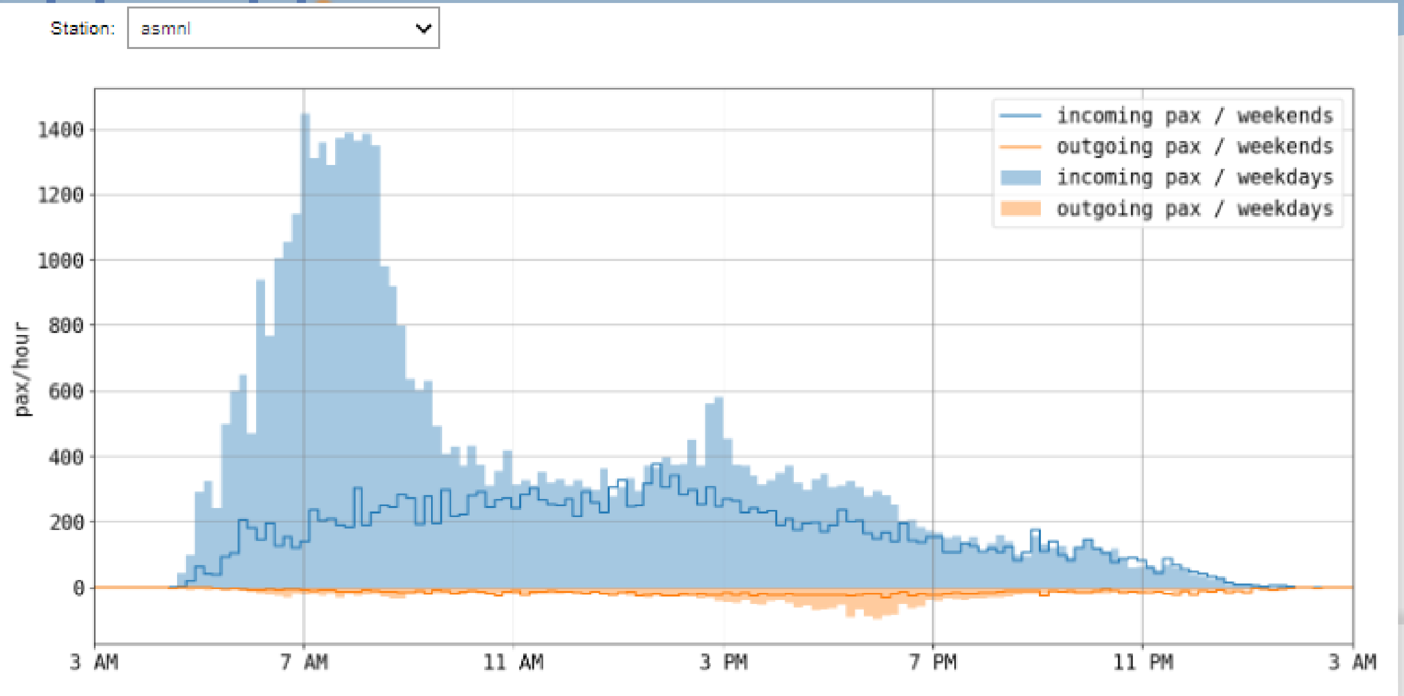
prototype implementation?



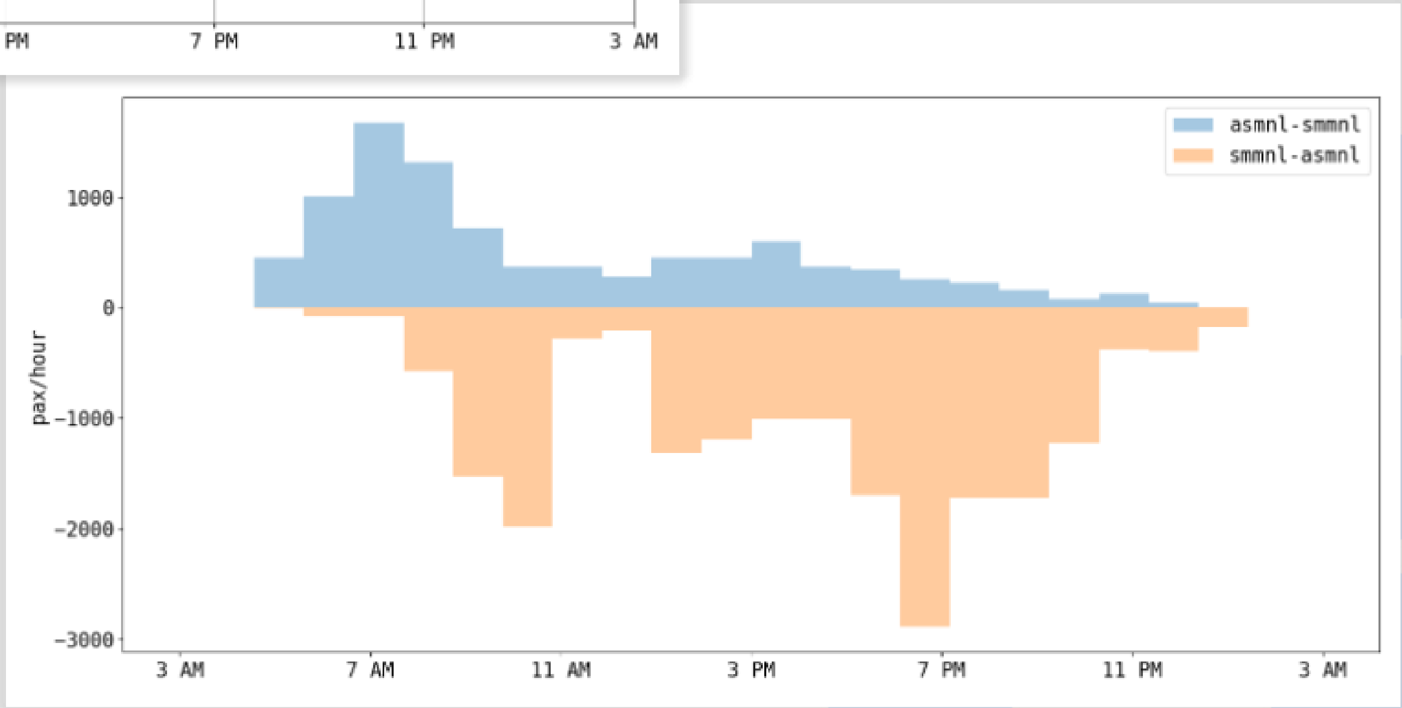




idea: use the state-space model and filter error covariance matrix for triggering feedback requests



input data (4-week average)
(outgoing pax not counted with turnstiles)



simulation output: Feb 25 2014
(on-board pax reaching terminus)

Summary:

$$x_k = F_k x_{k-1} + B_k u_k + w_k$$

- linear model of the dynamics of passenger loading in a transit network congruent with the underlying eqs. of the Kalman filter with control input

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- data fusion methodology for passenger and vehicle flows exemplified with the MTBAViz dataset

MoveWise prototype

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$$x_k = F_k x_{k-1} + B_k u_k + w_k$$

- linear model of the dynamics of passenger loading in a transit network congruent with the underlying eqs. of the Kalman filter with control input

- data fusion methodology for passenger and vehicle flows exemplified with the MTBAViz dataset

- data assimilation potential for vehicle weighing, APC, WiFi/GSM or real-time user feedback-based measurements

MoveWise prototype

Thank you for your attention!

free & open-source software used in implementation:
Jupyter, Python, numpy,
ipytest, ipywidgets, visJS2jupyter,
networkX, filterpy

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