Full-Day Accessibility Evaluation of Transit Systems Using GPS-Based Location Data

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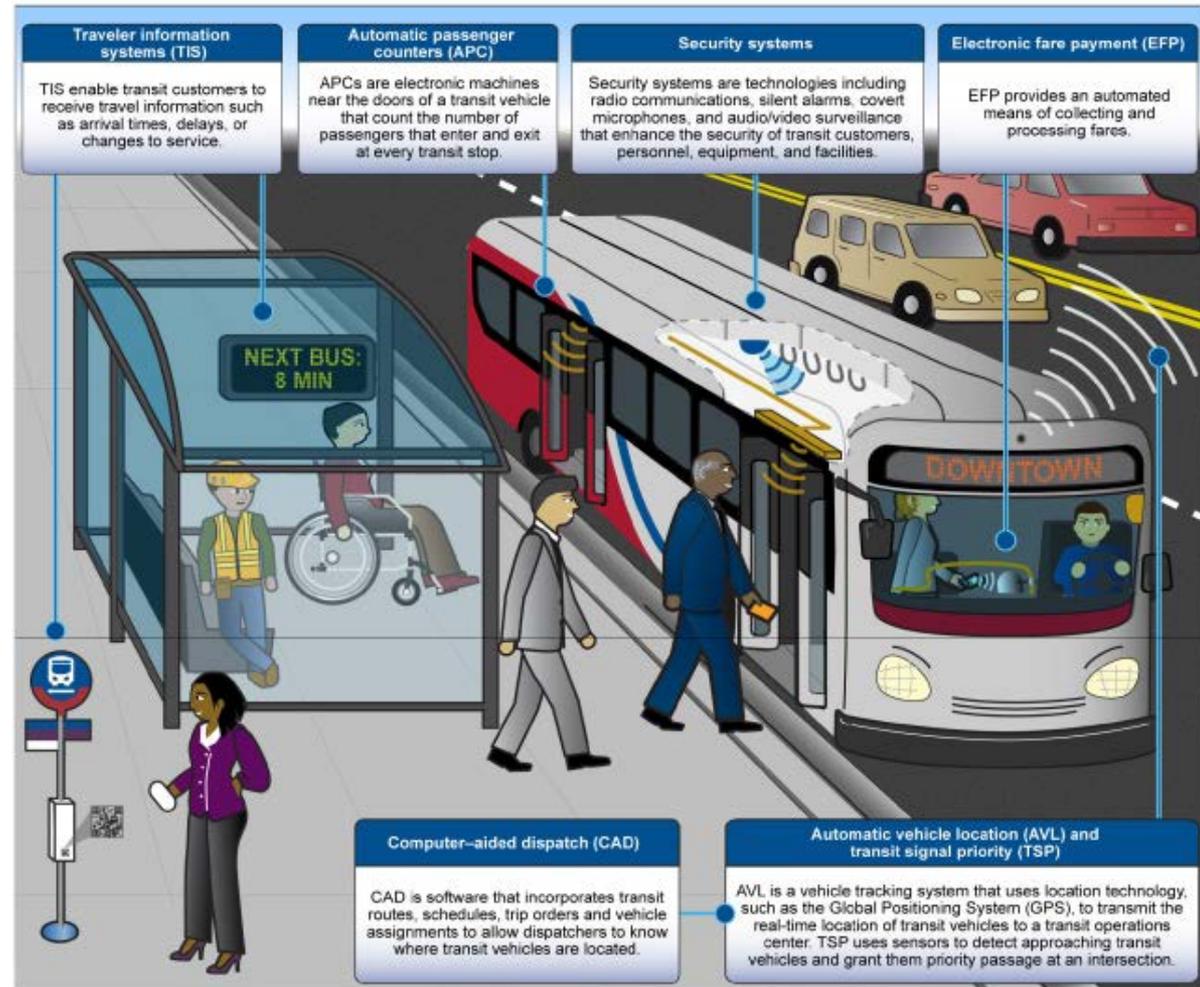
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Transit Intelligent Transportation System (ITS) Technologies

- **Automatic vehicle location (AVL)**

- **Automatic passenger counters (APC)**

- Traveler Information System (TIS)

- Electric fare payment

- Transit signal priority
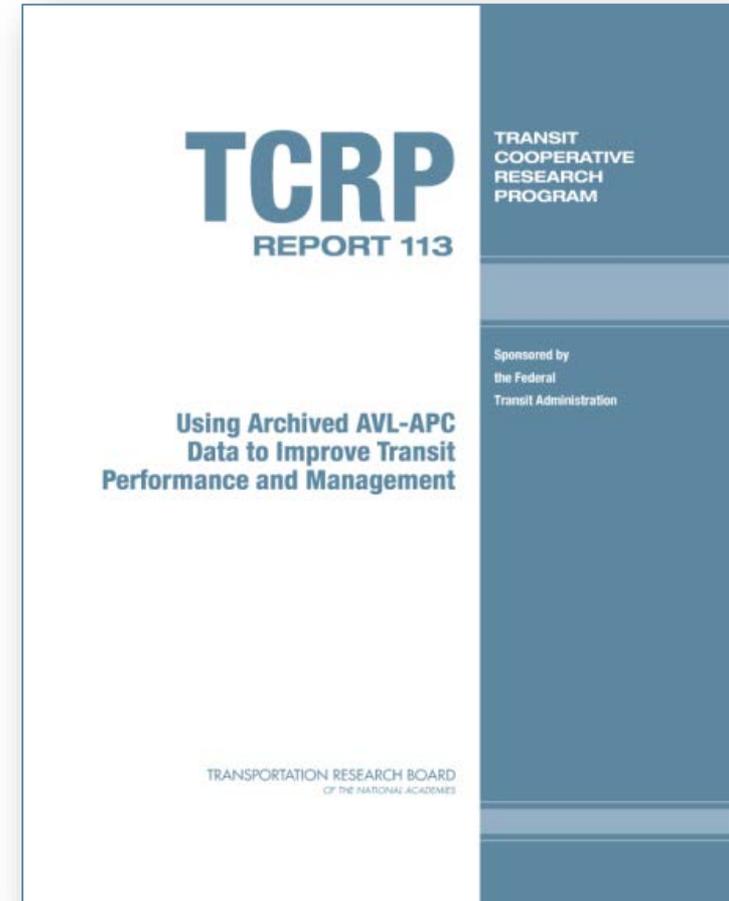
- Security systems

- Computer-aid dispatch

Traveler information systems (TIS)
TIS enable transit customers to receive travel information such as arrival times, delays, or changes to service.

Automatic passenger counters (APC)
APCs are electronic machines near the doors of a transit vehicle that count the number of passengers that enter and exit at every transit stop.

Security systems
Security systems are technologies including radio communications, silent alarms, covert microphones, and audio/video surveillance that enhance the security of transit customers, personnel, equipment, and facilities.

Electronic fare payment (EFP)
EFP provides an automated means of collecting and processing fares.

NEXT BUS: 8 MIN

DOWNTOWN

Computer–aided dispatch (CAD)
CAD is software that incorporates transit routes, schedules, trip orders and vehicle assignments to allow dispatchers to know where transit vehicles are located.

Automatic vehicle location (AVL) and transit signal priority (TSP)
AVL is a vehicle tracking system that uses location technology, such as the Global Positioning System (GPS), to transmit the real-time location of transit vehicles to a transit operations center. TSP uses sensors to detect approaching transit vehicles and grant them priority passage at an intersection.

Source: GAO analysis of Department of Transportation documentsGAO-16-638

❖ **Using AVL-APC data to improve transit performance & management**

- **Automatic vehicle location (AVL)**
  - ✓ primarily for real-time monitoring/control
  - ✓ not typically processed for off-line analysis

- **Automatic passenger counters (APC)**
  - ✓ provide passenger-activity data compatible with AVL operating data

- **Off-line analysis has substantial promise**
  - ✓ provide insights on transit performance
  - ✓ improve service planning and scheduling
  - ✓ promote transit ridership

reliable services & **accurate information**

TCRP
REPORT 113

TRANSIT
COOPERATIVE
RESEARCH
PROGRAM

Sponsored by
the Federal
Transit Administration

Using Archived AVL-APC Data to Improve Transit Performance and Management

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Board, T.R., (2006) National Academies of Sciences, E., Medicine: Using Archived AVL-APC Data to Improve Transit Performance and Management. The National Academies Press, Washington, DC

❖ **Improve transit accessibility**

- Fast and frequent services

- Sufficient service coverages

- First- and last- mile connection

- **Reliable schedule**
  - ✓ Better scheduled arrival times
  - ✓ Accurate real-time estimations

Portland TriMet

TransitTracker™
TriMet's real-time arrival information system

Chicago Transit

CTA Bus Tracker
Your official source for up-to-the-minute arrival info.

Metro Transit
Serving the Minneapolis / St. Paul Area

NexTrip

Get real-time departure times for your routes (?)

A Line - Northbound
Snelling & Larpenteur Station
Stop Number: 50010

NexTrip departs in **3 Min**

Current Time: 9:24 am

Route	Departs
A Line Rosedale/Rapid	3 Min
A Line Rosedale/Rapid	7 Min
A Line Rosedale/Rapid	18 Min
A Line Rosedale/Rapid	9:51
A Line Rosedale/Rapid	10:01
A Line Rosedale/Rapid	10:11

• Real Time • Scheduled

‹ BACK TO STOP   SHOW MY BUS ›

only at time stops (TS); accurate?

❖ Model Components

1. Linear-referencing

- ✓ allocate AVL and APC data along transit routes

2. Visual exploration

- ✓ <u>spatio-temporal patterns</u> of bus delays along routes

3. Semi-Markov process

- ✓ model vehicle movements as "jumping" processes from one stop to its next stop

- ✓ <u>calibrate "holding times"</u> for the "jump" between stops

AVL & APC database

Select records along a route during specific time periods

Separate records into trips and **sort** records along each trip by datetime

Bus routes & stops (edges and nodes)

Linear-reference records along each trip to its corresponding route

Clean up linear-referenced results (*time intervals, speed limits…*)

Visualize linear-referenced trajectories in space and time

by hour(s) of the day, day of the week, month, season, special time periods …

Points cover entire route?

Yes

Spatial-temporal patterns of delays

Calibrate holding time density function between consecutive bus stops (*sensitive to spatial-temporal patterns of delays*)

❖ **Method Highlights**

1. **Linear-referencing**
   ✓ discrete GPS coordinates ⇒ **an ordered sequence of placement along route**

   ✓ eliminate artificial movements due to device precision etc.

2. **Visual exploration**
   ✓ where and when are the delays ⇒ **at and between bus stops**

   ✓ traffic congestions, dwelling times, ...

   provide reference

3. **Semi-Markov process**
   ✓ recognize **ripple impacts of delays** along the trip

   ✓ sensitive to **traffic situation and ridership** during specific time periods

   support
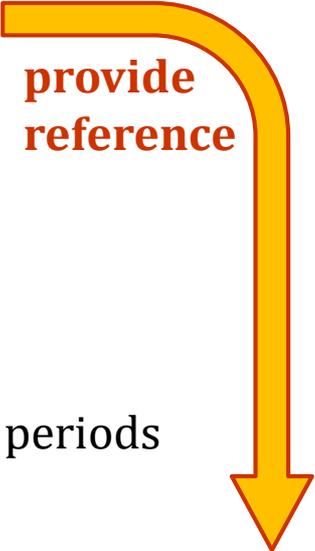
Use <u>AVL and APC data</u> to calibrate delays between each pair of bus stops.

A Pilot Study

❖ **Original Dataset**

- **A-Line**
  - ✓ every 10 minutes
  - ✓ pay ticket before boarding

- **AVL and APC data**
  - ✓ Oct. 1 to Oct. 8, 2016
  - ✓ 12 vehicles
  - ✓ 136,883 messages

Metro Transit *A Line*

▭	A Line (Rapid Bus Line)
▬	METRO Green Line (Light Rail)
▬	METRO Blue Line (Light Rail)
◉	Shared Station

Rosedale Transit Center

Snelling & County Road B

Snelling & Larpenteur

Snelling & Hoyt-Nebraska

Snelling & Como

Snelling & Hewitt

Snelling & Minnehaha

Snelling & University

Snelling & Dayton

Snelling & Grand

Snelling & St Clair

Snelling & Randolph

Snelling & Highland

Rosedale Center

County Rd B

Har Mar Mall

ROSEVILLE

Larpenteur

State Fairgrounds

Como

ST PAUL

Hamline University

Minnehaha

Grand

Macalester College

MINNEAPOLIS

MISSISSIPPI RIVER

46th Ave

Cleveland

Fairview

Ford Pkwy

ST PAUL

46th St

46th St Station

46th St & Minnehaha

46th St & 46th Ave

Ford & Woodlawn

Ford & Finn

Ford & Kenneth

Ford & Fairview

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1. Linear Referencing

(**longitude, latitude**, timestamp, …) ⇒ (**route, distance from first stop**, time stamp, …)
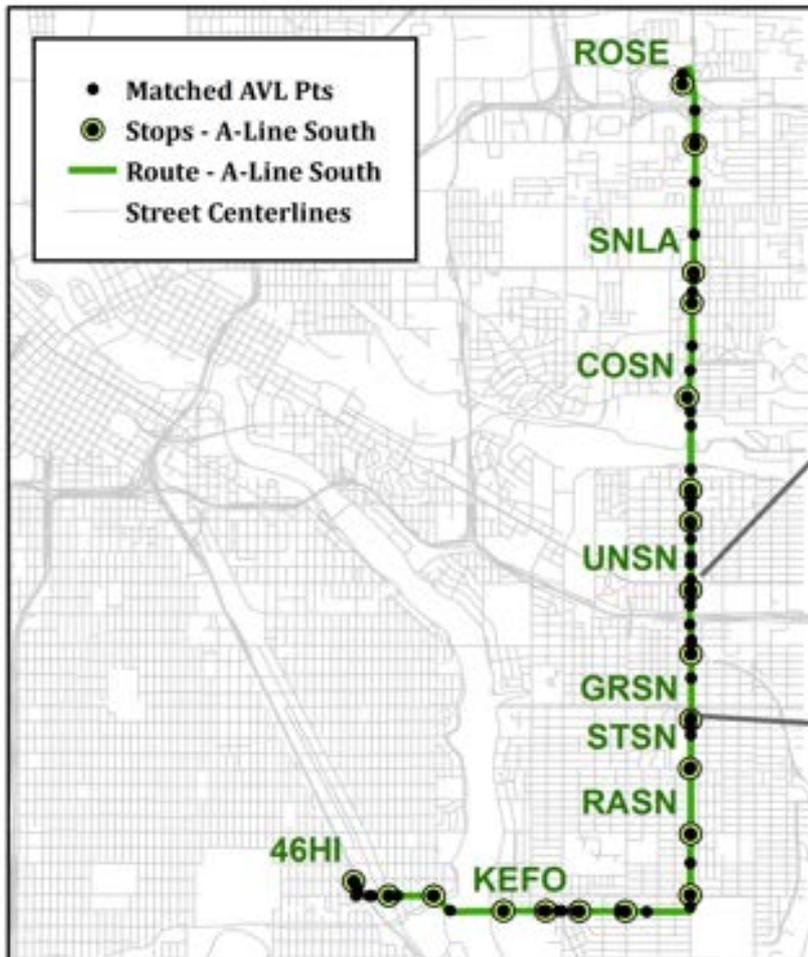
deal with "back-forth" movements

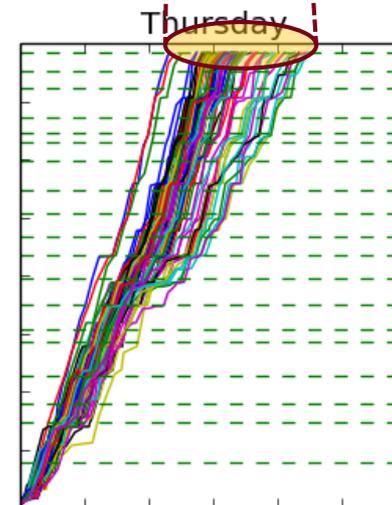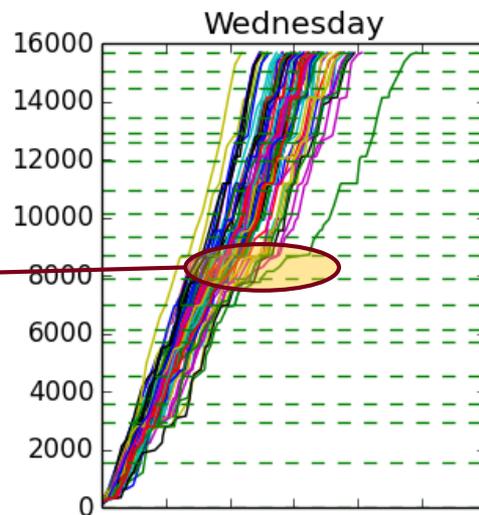# Results

2. **Visual exploration** – day of the week

different variations
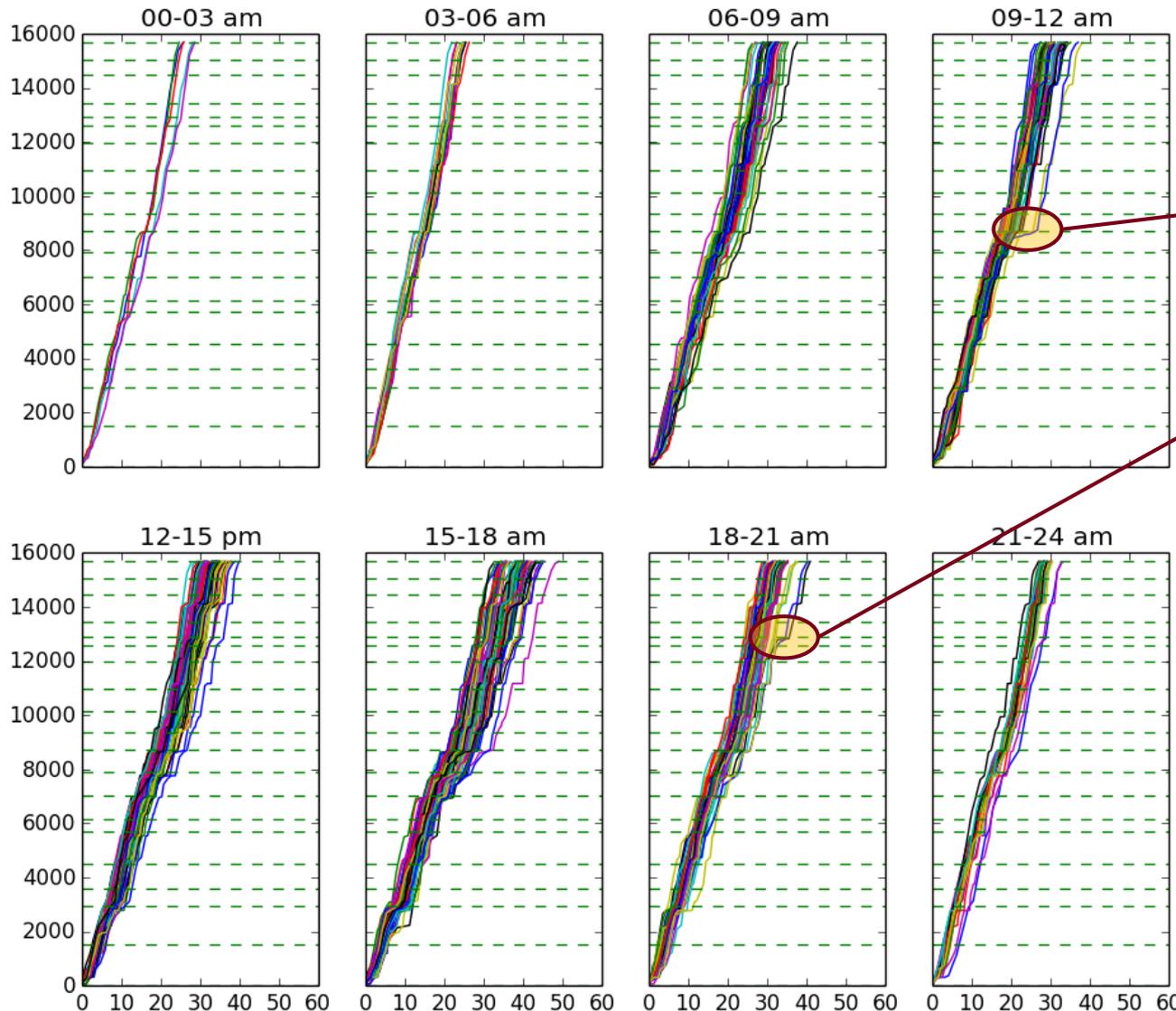
less variation
less delays
⇒
more reliable
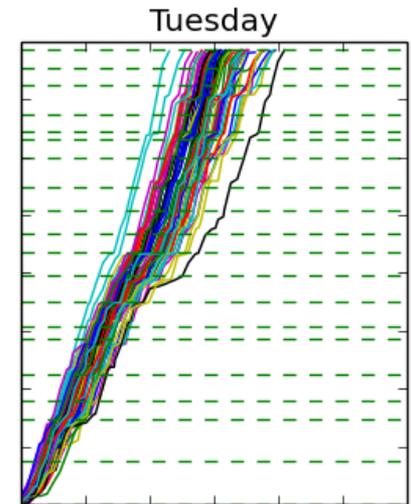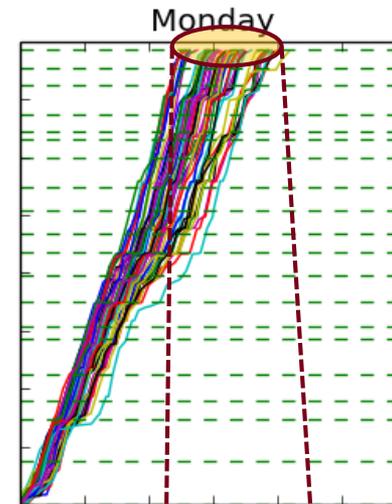
where lead to
more delays
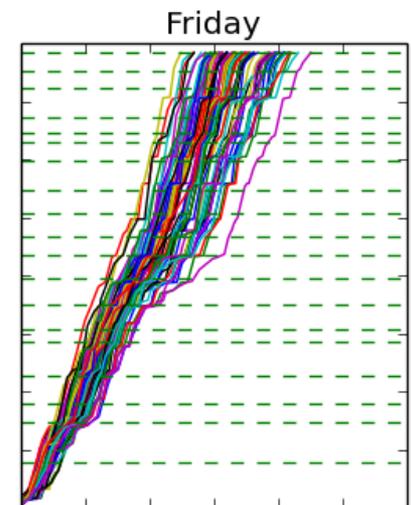
Macalester College
& University Ave W

2. Visual exploration – hour of the day

where & where has more delays

Macalester College & University Ave W 9am – 12pm

Near Cleveland Ave S & Ford Pkwy cross 6pm – 9pm

consistent with afternoon peak hours for traffic

3. **Calibrate delays between stops**

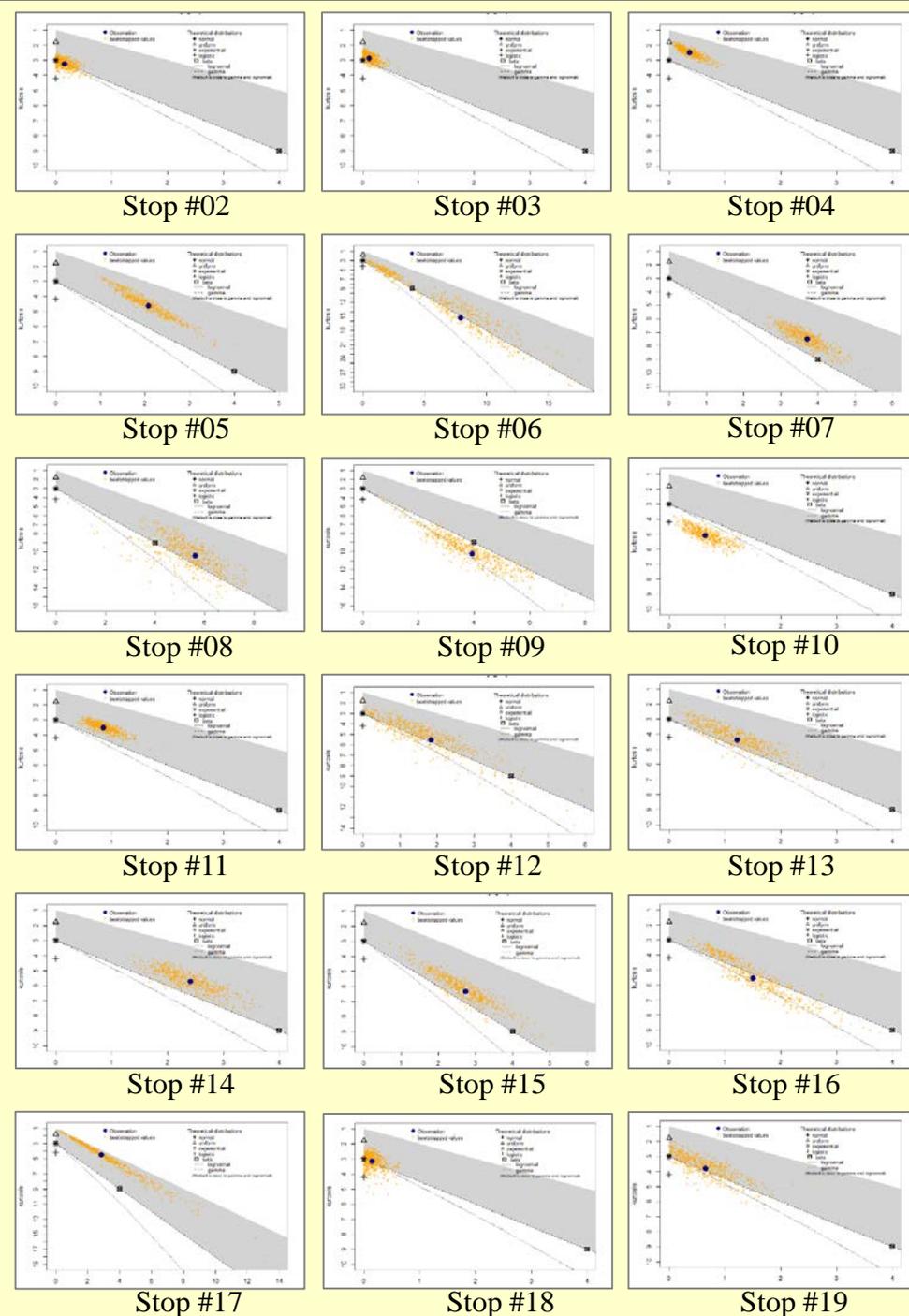**1)** **kurtosis (variability)** and **squared skewness (location)** of empirical delays

Cullen and Frey graph
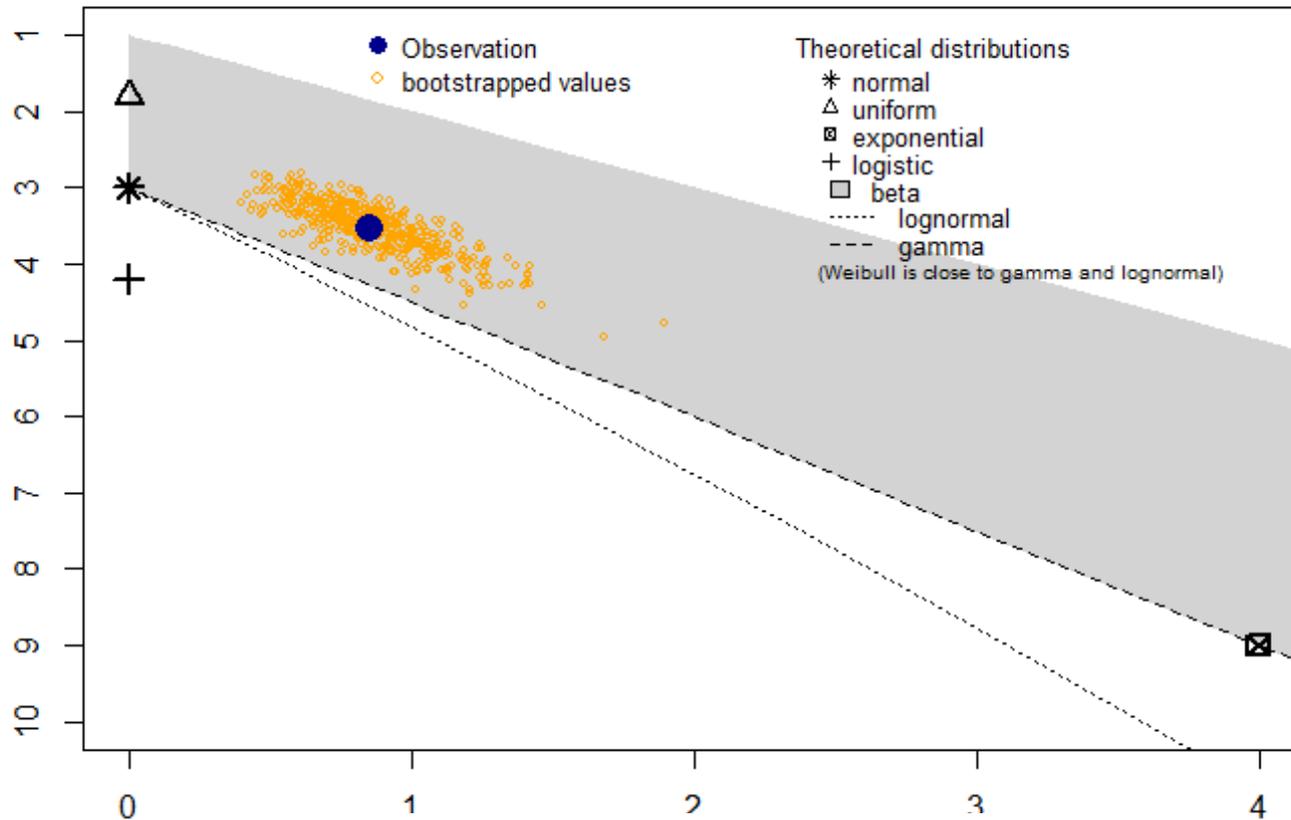
Results

3. Calibrate delays between stops

**Lognormal & Gamma distribution**

- Patterns are slightly different along trips between two stops

- **Beginning and end** of the trip tend to have **low kurtosis**
  ⇒ less outliers (long delays)

- **Towards the middle** of the trip, the **skewness is larger**
  ⇒ not symmetrically distributed

R Packages

Stop #02 Stop #03 Stop #04
Stop #05 Stop #06 Stop #07
Stop #08 Stop #09 Stop #10
Stop #11 Stop #12 Stop #13
Stop #14 Stop #15 Stop #16
Stop #17 Stop #18 Stop #19

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R Packages

3.   Calibrate delays between stops

2) Compare empirical and theoretical fitted distribution <maximum likelihood>

Mean = 56.26 seconds
Std.   =   2.01 seconds

Wednesday at stop #11 near Macalester College

Discussion
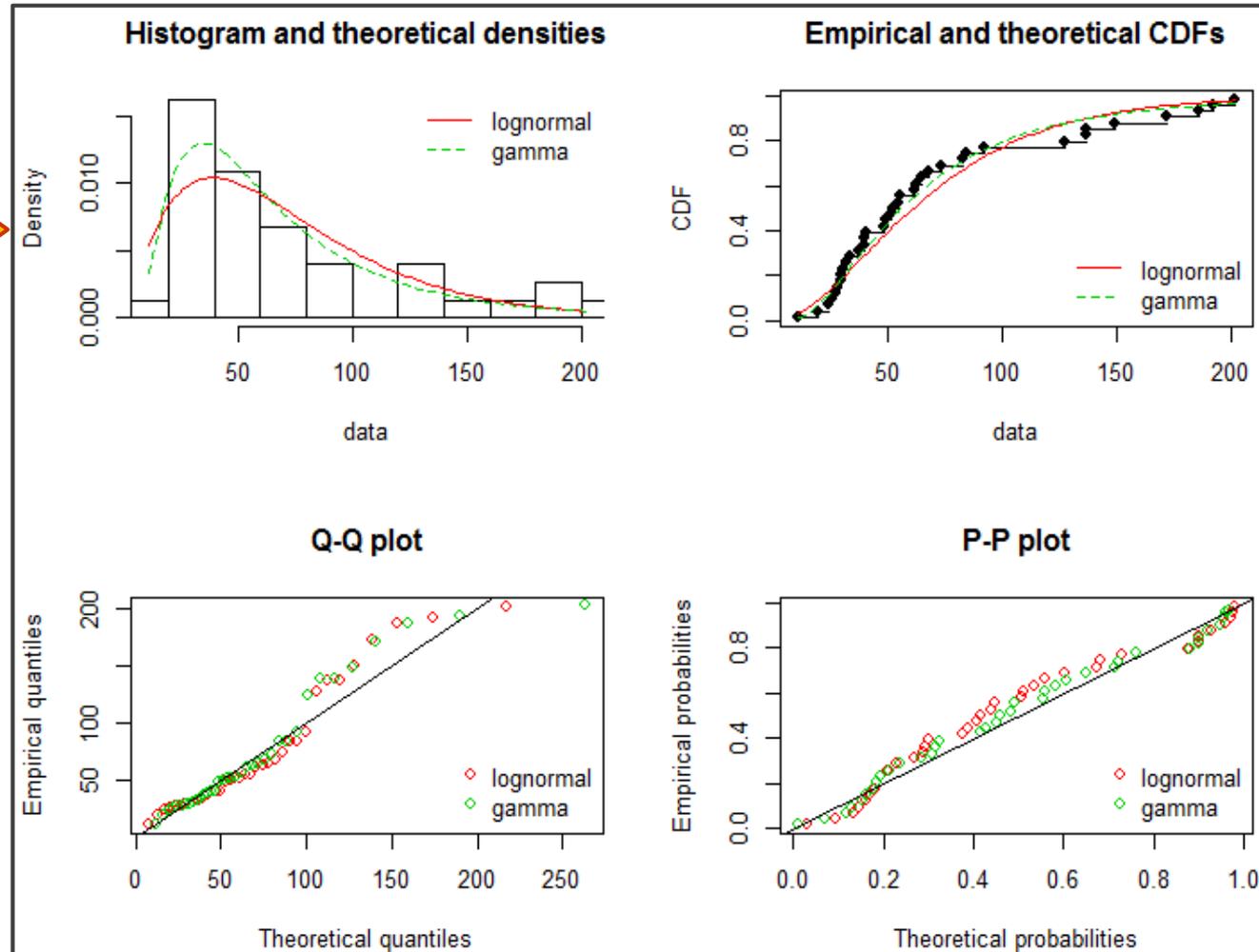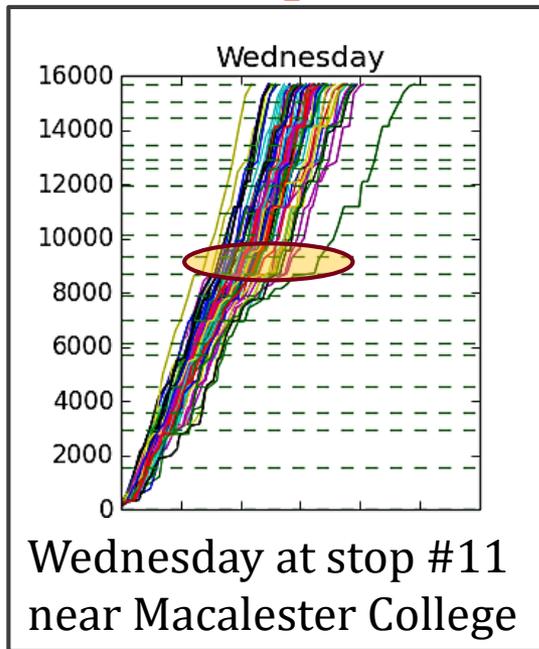
❖ **Results Highlights**

- Visualizing linear referenced trips can reveal **spatial-temporal patterns of vehicle delays** along the routes, and **identify locations and/or times** that lead to delays

- Along A-Line route, delays during weekdays fit best with **lognormal and gamma distribution** for movements between any two consecutive stops; yet the patterns are slightly difference with respect to **location and variability** of empirical delays

❖ **Practical Merits**

- **Adjust bus schedules** to reflect the revealed delay patterns

- Provide **more accurate arrival time estimations** to transit users that can
  - recognize that the delays between two stops may not be the same
  - capture the ridership and traffic "congestions" during different time periods

- **Refine current transit accessibility measures** to consider expected/mean delays at stops in addition to the scheduled service time and frequency

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This material is based upon work supported by CTS Seed Fund

The supplementary data is provided by Metro Transit

1. Jump Rate

$$p_{ij} = \begin{cases} 1 & t_{ij} < t_j^+ - t_i^- \\ 0 & otherwise \end{cases}$$

2. Holding Time– reach e_{ij} from v_i at time t

$$p_i(t) = \begin{cases} 0 & , & t \in [t_O, t_i^-) \\ \int_{t_i^-}^{t} \lambda e^{-\lambda \tau} d\tau = e^{-\lambda t_i^-} - e^{-\lambda t} & , & t \in [t_i^-, t_j^+ - t_{ij}) \\ \int_{t_i^-}^{t_j^+ - t_{ij}} \lambda e^{-\lambda \tau} d\tau = e^{-\lambda t_i^-} - e^{-\lambda(t_j^+ - t_{ij})}, & & t \in [t_j^+ - t_{ij}, t_D] \end{cases}$$

3. State probability

$$Prob(e_{ij}, t) = p_{ij} * p_i(t) * p_j(t)$$

Based 1: the estimated NTP

$$RMSE^1(t) = \frac{\sum_{\{e_{ij}\}^t} \left(EmpP_{(e_{ij},t)} - SimP_{(e_{ij},t)} \right)^2}{Cnt(t)}$$

$\{e_{ij}\}^t$: edges within NTP at time t

$\{SimP_{(e_{ij},t)}\}$ simulated visit probabilities

$\{EmpP_{(e_{ij},t)}\}$ empirical visit probabilities

Based 2: the empirical NTP traces

Further select from $\{e_{ij}\}^t$: edges have been used by at least one GPS trace