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Arterial Travel Time Characterization and Real-time Traffic Condition Identification Using GPS-equipped Probe Vehicles

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Outline

- Introduction
- Characterization of Arterial Travel Time
- Link Travel Time Distribution Estimation
- Mean Route Travel Time Estimation
- Real-time Traffic Condition Identification
- Conclusions

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Introduction

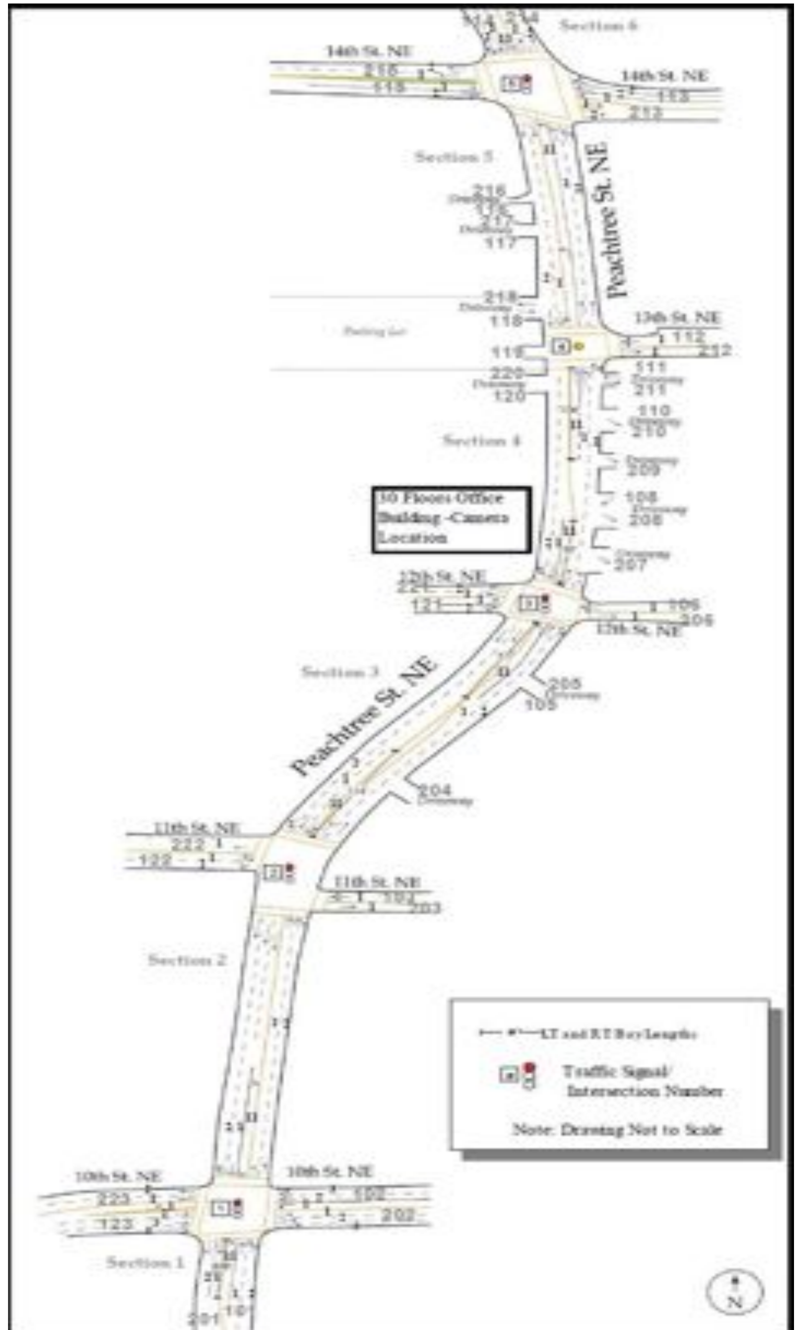
- Travel time is a crucial variable both in traffic demand modeling and network performance measurement.
- Problem with Analytical models (eg. BPR function): only provide average travel time for all vehicles
- Travel time for individual Vehicle is needed

Introduction

- Monitoring system on arterials has lagged behind what is done on freeways, due to the size of urban arterial systems.
- Solution: using already-deployed sensors such as GPS equipped vehicles

Introduction

- NGSIM Program
- Peachtree St Dataset
- Section 2 – Section 5
- Two traffic conditions: Noon and PM



Characterization of Arterial Travel Time

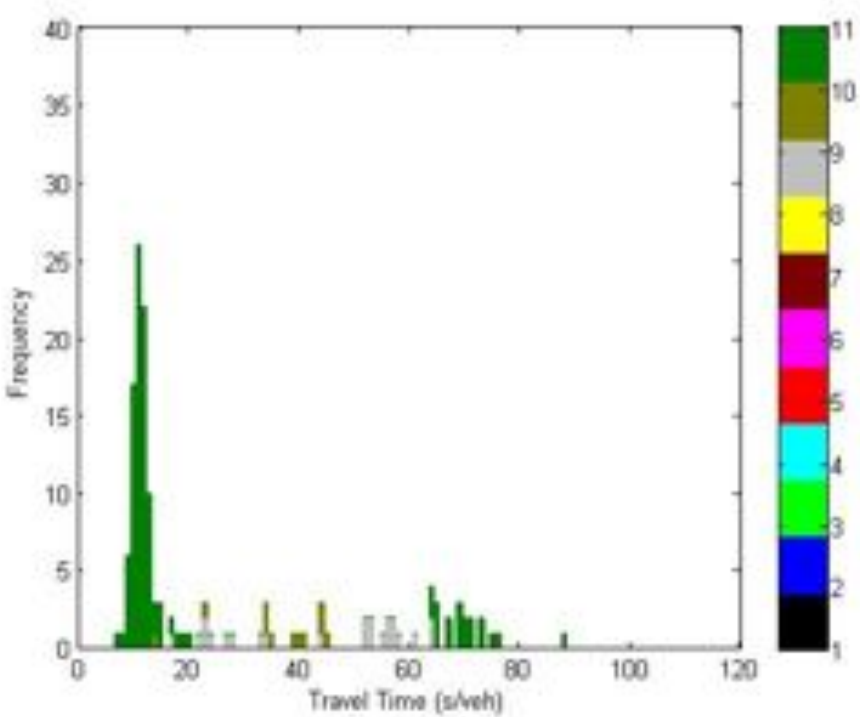
The main factors that affect travel time:

- Geometric structure of the arterial
- Driving behaviors
- Signal control strategy
- Traffic demand

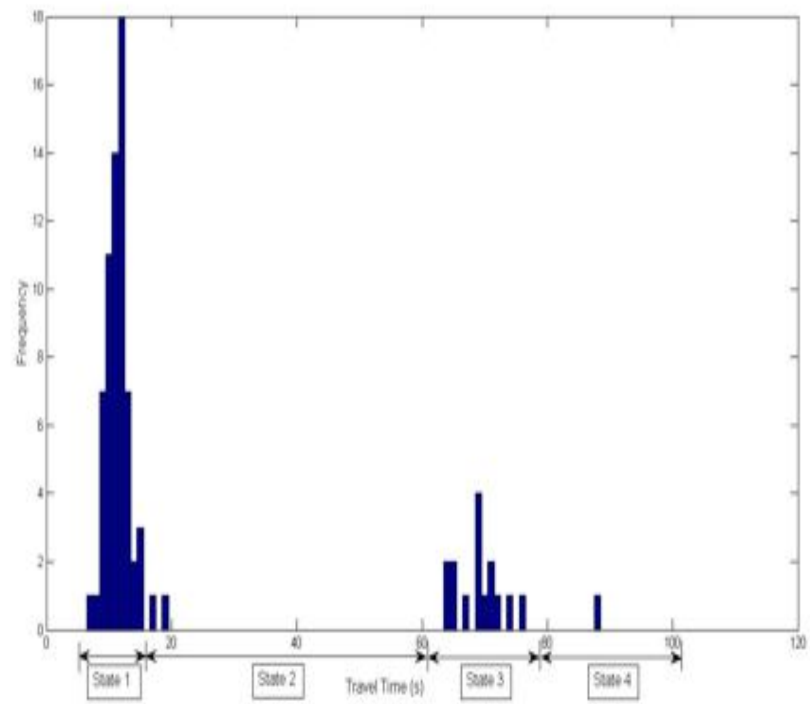
Characterization of Arterial Travel Time

- Travel time histograms of NGSIM data
- Section 2 Northbound at Noon

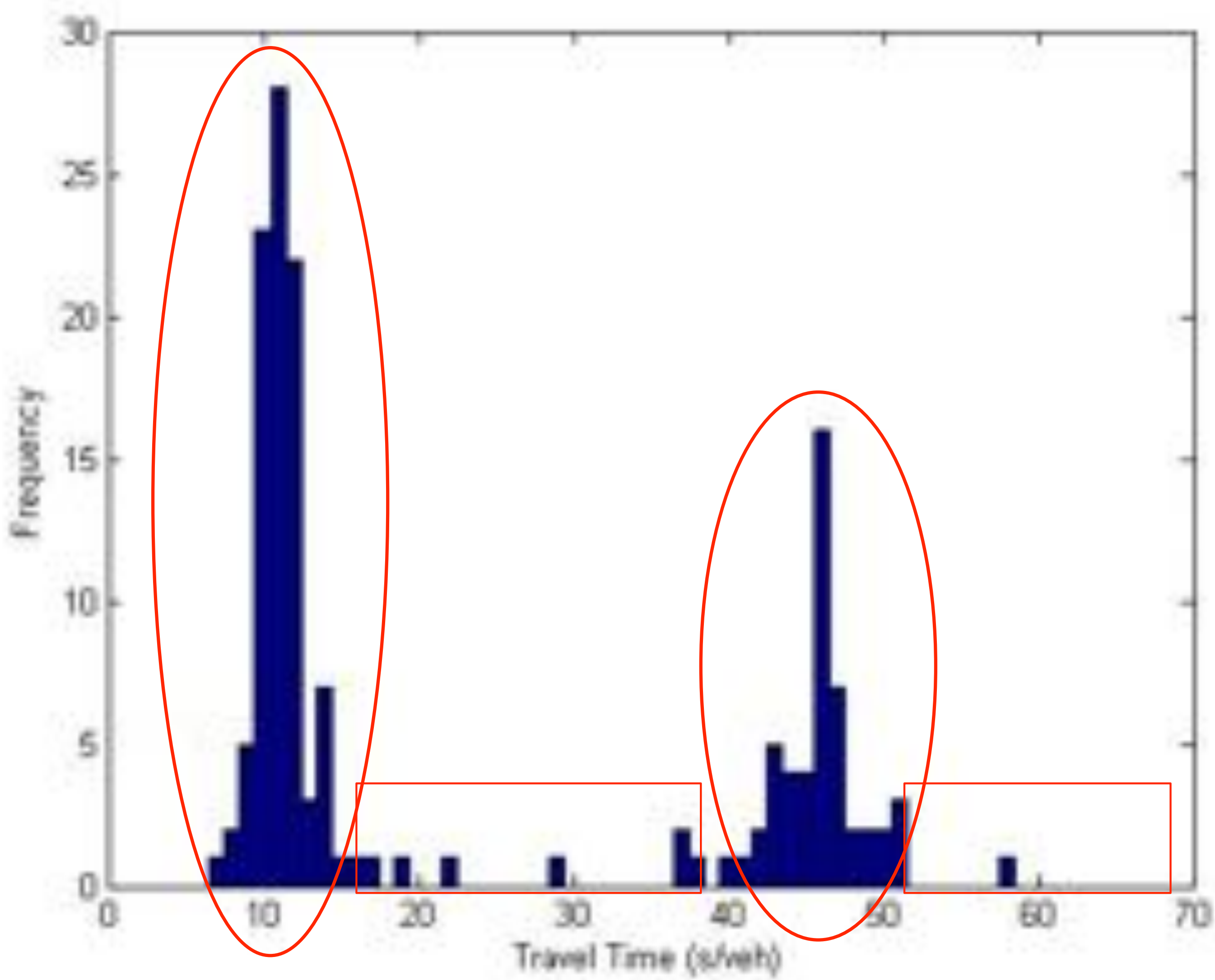
All vehicles



Through-through vehicles



Characterization of Arterial Travel Time



Characterization of Arterial Travel Time

Four states of travel time:

- State 1: non-stopped,
- State 2: non-stopped with delay,
- State 3: stopped,
- State 4: stopped with delay.

Travel time distribution Estimation

- Mixture normal density (State 1, 3)

$$f(TT) = p \times f_n(TT) + (1-p) \times f_s(TT)$$
$$f_n(TT) \sim N(\mu_1, \sigma_1^2)$$
$$f_s(TT) \sim N(\mu_2, \sigma_2^2)$$

- Parameters: $\psi(p, \mu_1, \sigma_1^2, \mu_2, \sigma_2^2)$

Construction of likelihood

- Group travel time into *m* sub-intervals

$$m = round(TT_{max} - TT_{min}) + 1$$

- Let $n_1 \ldots n_m$ be the number of travel time that falls into intervals $[a_0, a_1], \ldots, [a_{m-1}, a_m]$
- The probability that an individual vehicle travel time falls in the j^{th} interval:

$$P_j(\psi) = \int_{a_{j-1}}^{a_j} f(TT|\psi)\, dTT, j = 1, \ldots, m$$

Construction of likelihood

- The grouped data follow a multinomial distribution:

$$L(\psi) = \frac{n!}{n_1! \dots n_m!} \{P_1(\psi)\}^{n_1} \dots \{P_m(\psi)\}^{n_m}$$

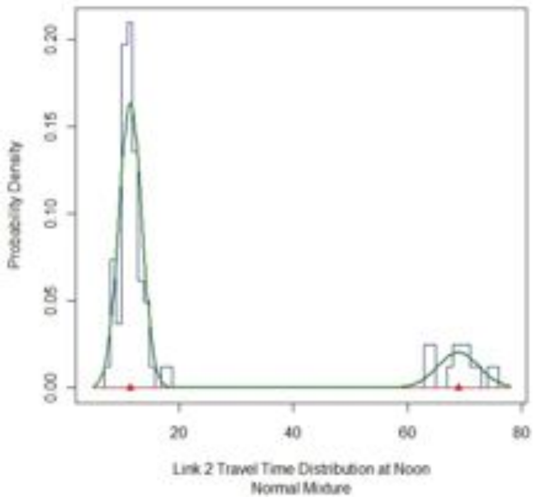
- log-likelihood:

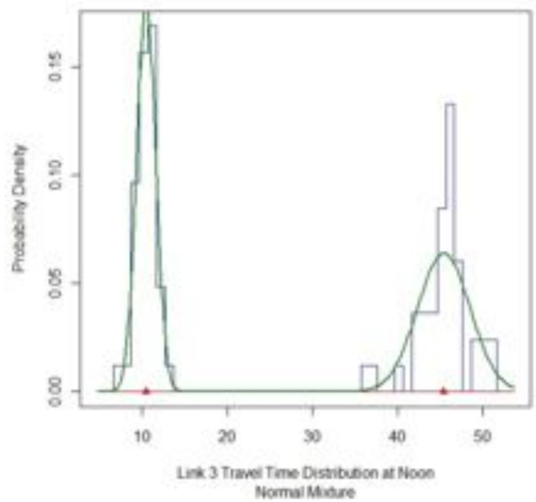
$$log\ L(\psi) = \sum_{j=1}^{m} n_j log(P_j(\psi)) + log(\frac{n!}{n_1! \dots n_m!})$$

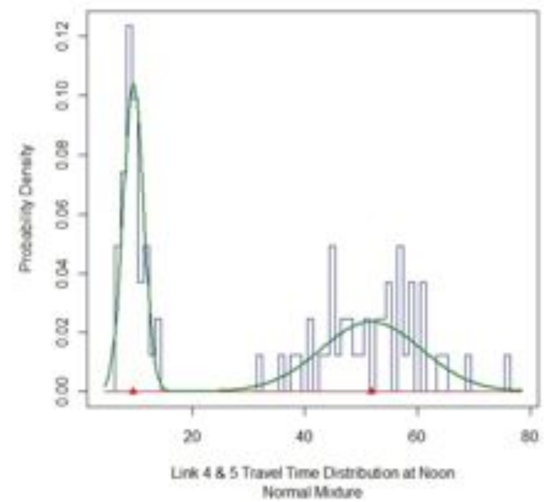
- Maximum likelihood estimation (R)

Travel time distribution Estimation

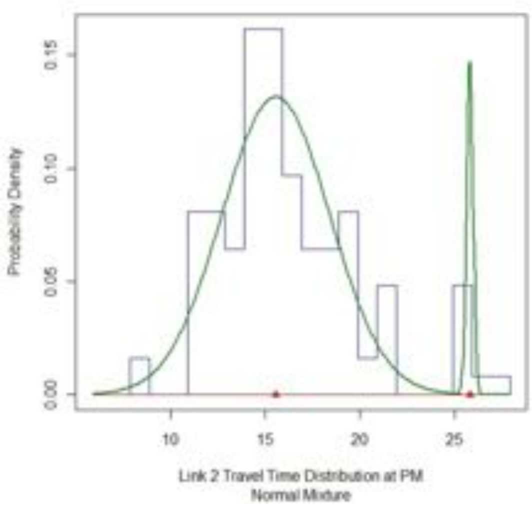
Noon

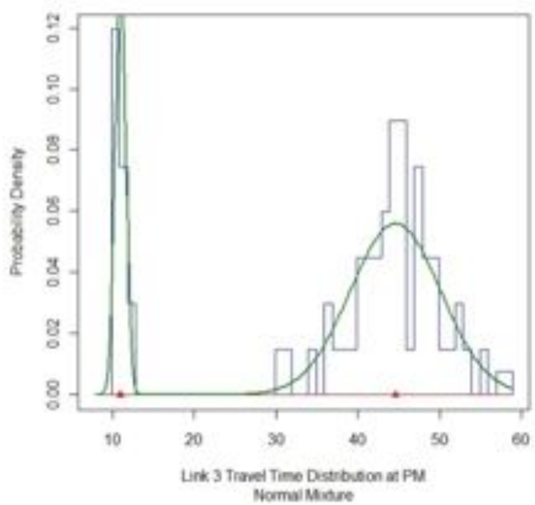


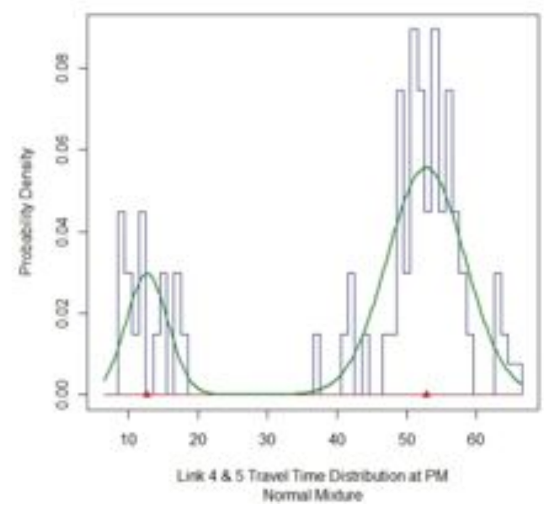




PM







Mean Route Travel Time Estimation

- Route travel time consists of successive link travel times
- Travel time state of each section is not independent to each other
- Markov property: travel time of the current section is only dependent on the immediate upstream section
- Markov Chain

Mean Route Travel Time Estimation

- System States:

1: non-stop vehicles 2: non-stop vehicles with delay

3: stopped vehicles 4: stopped vehicles with delay

- Transition matrix:

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{14} \\ p_{21} & p_{22} & \cdots & p_{24} \\ \vdots & \vdots & & \vdots \\ p_{41} & p_{42} & \cdots & p_{44} \end{pmatrix}$$

- Initial Distribution

Mean Route Travel Time Estimation

- Joint probability of all steps is the product of the transit probability of each step

$$P\{S_0 = i_0, S_1 = i_1 \cdots, S_n = i_n\} = \lambda_{0i} p_{i_0 i_1} p_{i_1 i_2} \cdots p_{i_{n-1} i_n}$$

- Mean route travel time:

$$TT_{route} = \sum_{i_1=1}^{4} \sum_{i_2=1}^{4} \cdots \sum_{i_n=1}^{4} \left(T_{i_1}^{(1)} + T_{i_2}^{(2)} + \cdots + T_{i_n}^{(n)} \right) \times p_{i_0 i_1} \times p_{i_1 i_2} \times \cdots \times p_{i_{n-1} i_n}$$

Mean Route Travel Time Estimation

- Numerical Example: NGSIM Peachtree St Dataset at Noon
- Estimated mean travel times of different states in each link

	State 1	State 2	State 3	State 4
Link 2	11.29	38.12	68.87	88.08
Link 3	10.49	26.02	45.47	75.82
Link 4	9.54	N/A	N/A	N/A
Link 5	9.58	23.47	51.76	84.88

Mean Route Travel Time Estimation

- **Case I: Given the vehicle is a non-stopped vehicle at the entrance**

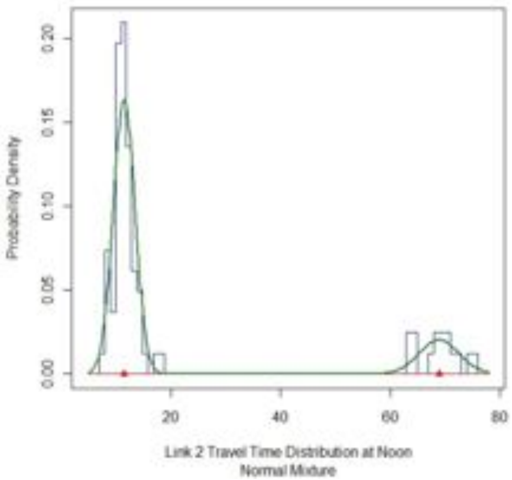
The mean travel time estimated by the model is 108.89s. The mean travel time from the data is 110.78s, and an approximate 95% confidence interval is (97.16s; 124.40s).

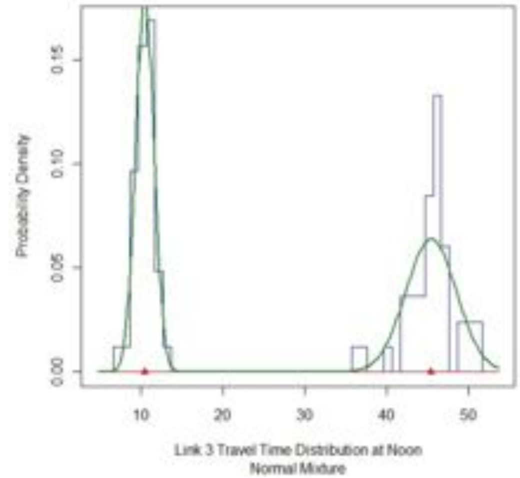
- **Case II: Given the vehicle is a stopped vehicle at the entrance**

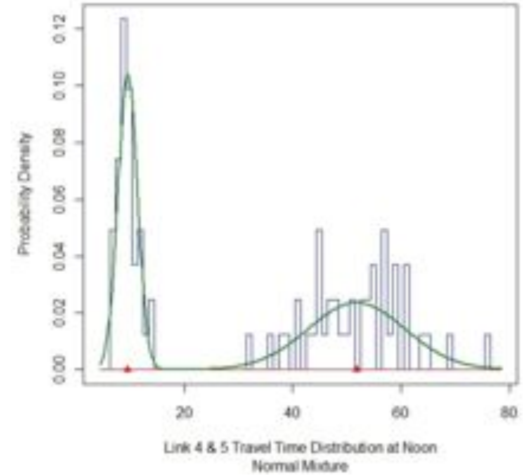
The mean travel time estimated by the model is 87.4s. The mean travel time from the data is 86.25s, with a approximate 95% confidence interval of (79.59s; 92.91s).

Traffic Condition Identification

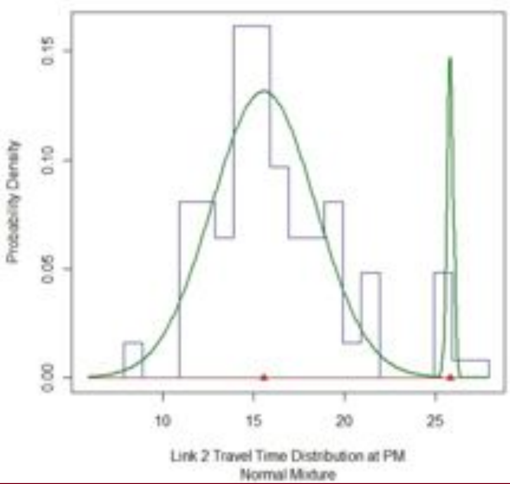
Noon

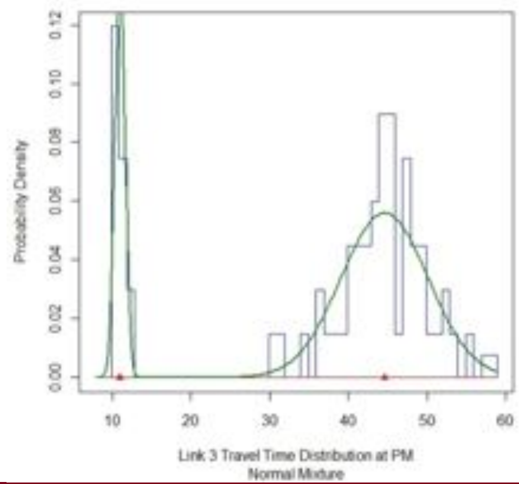


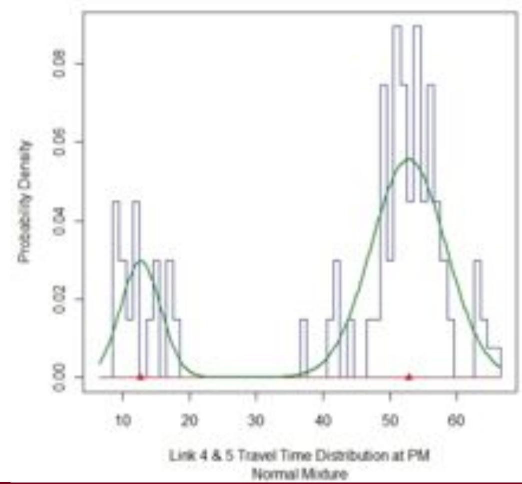




PM







Traffic Condition Identification

- The probabilities that a travel time sequence belongs to each traffic condition can be calculated using Bayes Theorem.
- The joint probability of travel time states could be expressed by the following equation:

$$
\begin{aligned}
P(S_1 = s_1, S_2 = s_2, \ldots, S_n = s_n) = P(S_n = s_n | S_{n-1} \\
= s_{n-1}, \ldots, S_2 = s_2, S_1 = s_1) \times P(S_{n-1} \\
= s_{n-1} | S_{n-2} = s_{n-2}, \ldots, S_2 = s_2, S_1 \\
= s_1) \times \cdots \times P(S_2 = s_2 | S_1 = s_1) \times P(S_1 = s_1)
\end{aligned}
$$

Traffic Condition Identification

- Assuming the travel time of a single link is independent of travel time states in other links:

$$P(T_i = t_i | S_1 = s_1, S_2 = s_2, \dots, S_i = s_i, \dots, S_n = s_n) = P(T_i = t_i | S_i = s_i)$$

- The join distribution of travel time and travel time states can be seen:

$$P(T_1 = t_1, \dots, T_n = t_n, S_1 = s_1, \dots, S_n = s_n) = \left(\prod_{i=1}^{n} P(T_i = t_i | S_i = s_i) \right) P(S_1 = s_1, \dots, S_n = s_n)$$

Traffic Condition Identification

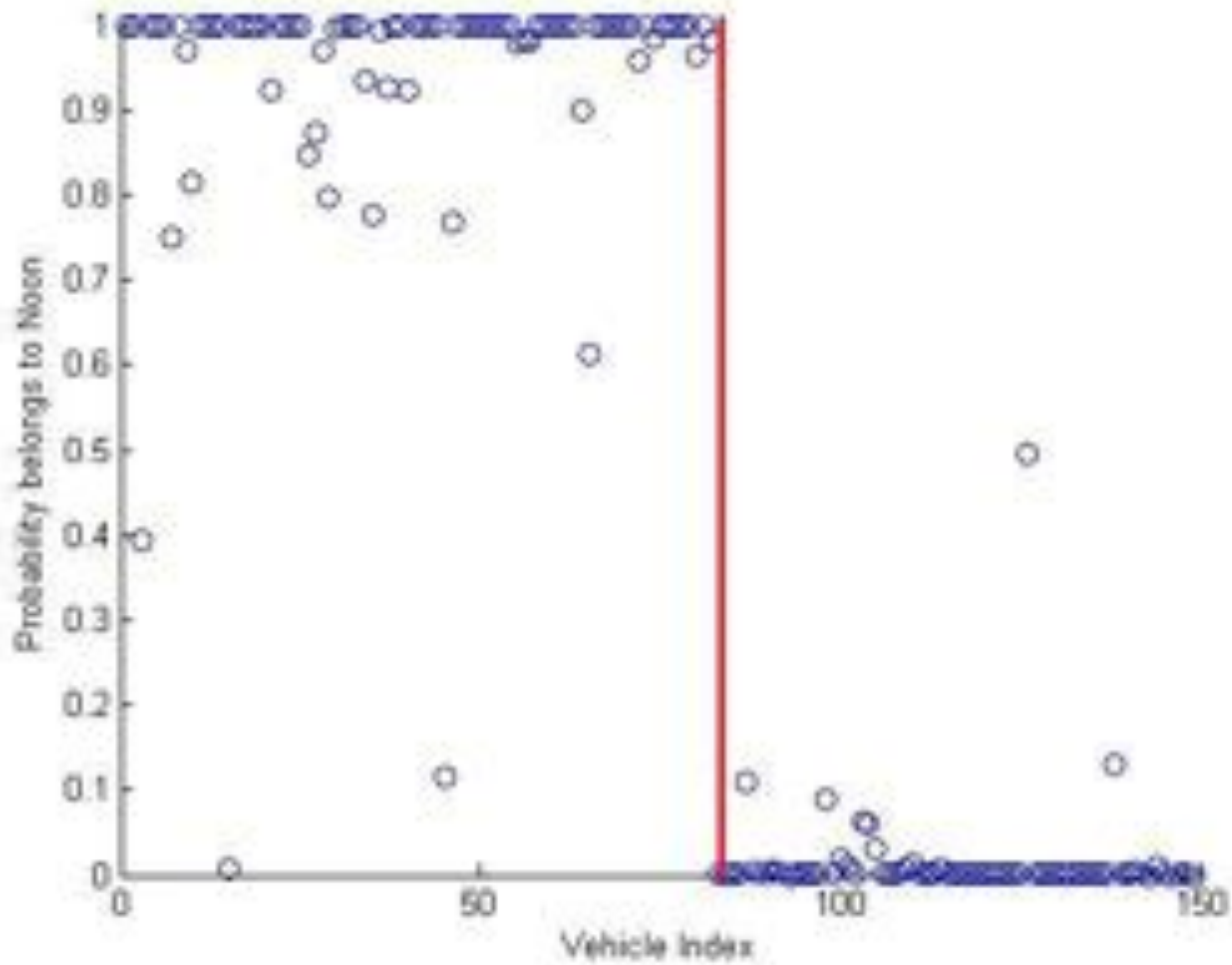
- So the marginal distribution for travel times becomes

$$P(T_1 = t_1, \dots, T_n = t_n) = \sum_{S_1=s_1,\dots,S_n=s_n} \left(\prod_{i=1}^{n} P(T_i = t_i | S_i = s_i)\right) P(S_1 = s_1, \dots, S_n = s_n)$$

- Assuming there are *m* different traffic conditions, the probability that a given travel time sequence belongs to traffic condition C_i

$$P(C_i | T_1 = t_1, \dots, T_n = t_n) = \frac{P(T_1=t_1,\dots,T_n=t_n | C_i) \times P(C_i)}{\sum_{j=1}^{m} P(T_1=t_1,\dots,T_n=t_n | C_j) \times P(C_j)}$$

Traffic Condition Identification



Conclusions

- Four travel time states for through-through vehicles
- Fit travel time distribution with mixture normal densities (EM)
- Propose a Markov Chain model to estimate mean route travel time
- Identify real-time traffic condition (only GPS data from 1-2 vehicles)

Acknowledgement

The authors would like to acknowledge the Federal Highway Administration for providing NGSIM data for public use freely.

Thank you!

Questions?