Evaluating Recurring Traffic Congestion Using Change Point Regression and Random Variation Markov Structured Model

Presented by: Emmanuel Kidando

Emmanuel Kidando[1], Ren Moses[1], Thobias Sando[2] & Eren E. Ozguven[1]
[1]Department of Civil and Environmental Engineering,
FAMU-FSU College of Engineering,
2525 Pottsdamer Street, Tallahassee, FL 32310.
[2]University of North Florida, College of Engineering,
1 UNF Drive, Jacksonville, FL 32224.

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Presentation Overview

- Introduction
- Research objective
- Study site
- Data
- Methodology
- Results and Discussion
- Conclusions
- Future Work

Introduction

Mobility

- Travel delay of nearly 7 billion hours
- Total cost of congestion was $ 160 billion

Environment

- Wasted more than 3 billion gallons of fuel

Urban Mobility Scorecard report (Schrank, *et al.*, 2015)

Introduction

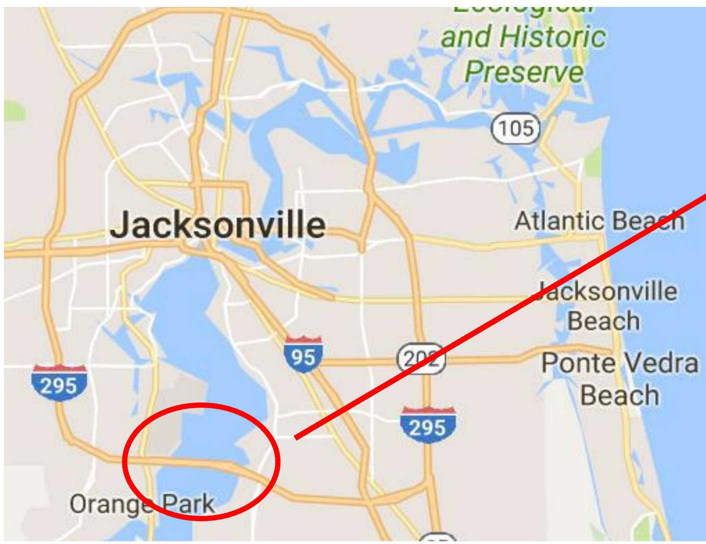
- Success of alleviating traffic congestion through operation efficiency depends on:
    - Quality of the data used for evaluation and prediction
    - Predictive capability of the model
    - Dissemination of the accurate and timely traffic information to road users

Research Objective

- The study proposes a probabilistic framework to evaluate the dynamic evolution process of recurring traffic congestion on a basic freeway segment
    - Bayesian change point regression to estimate speed threshold
    - Markov Chain Structure regression to estimate the dynamic evolution of recurring congestion

Study site

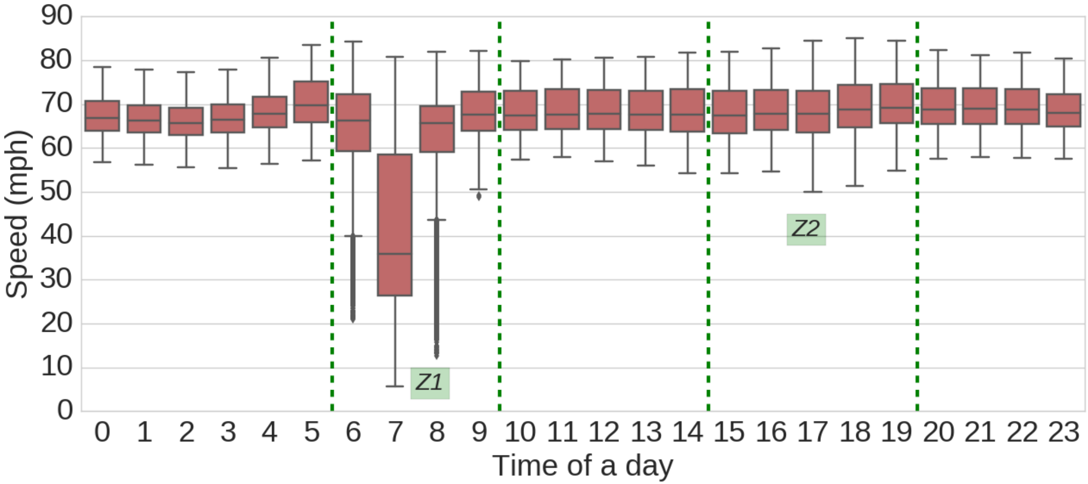
A section of Interstate 295 in Jacksonville



- 4.8-miles basic freeway segment
- 65 mph posted speed limit
- One year traffic data were used in the analysis (2015)

Data

- Hourly speed profile for the study segment



- Morning peak period (6am – 9am)
- Evening peak period (3pm – 7pm)

Methodology

- To evaluate the dynamic evolution of recurring traffic congestion, four steps were applied in the modeling process;

Step 1

Traffic data for Analysis
- Morning Peak Hours
- Evening Peak Hours

Step 2

Traffic regimes Identification
- Speed Thresholds

Step 3

Developing Markov Chains Matrix
- Markov Chains Memory Length Identification

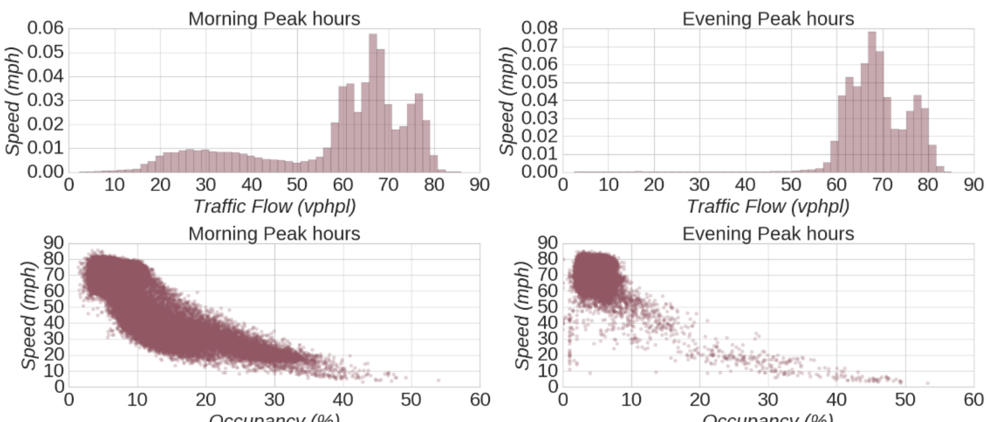
Step 4

Dynamic Evolution modeling of Recurring Traffic Congestion
- Random Variation Markov Structured Regression Model

Methodology

Bayesian change point regression model

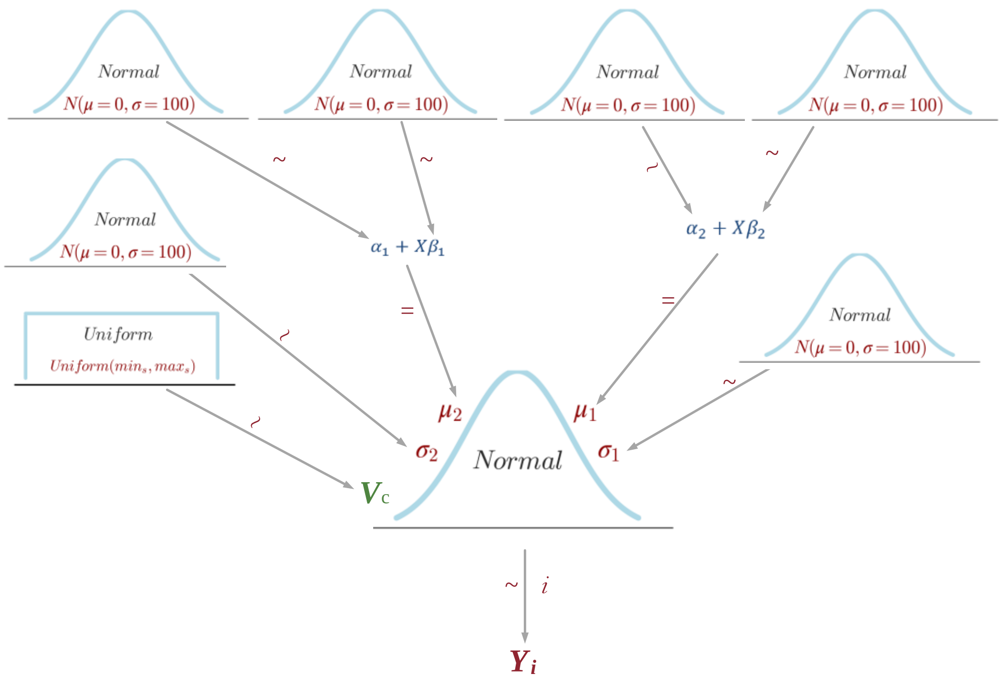
- A model that was used to estimate a speed threshold where patterns before and after the threshold are significantly different



- Non-linear relationship between speed and occupancy
- The two regressions are separated by the critical point called critical speed threshold

Methodology

Bayesian change point regression model



$$Y \sim \text{Normal}\left(\alpha_1 + X\beta_1, \sigma_2\right)\ if\ X \le V_c$$
$$Y \sim \text{Normal}\left(\alpha_2 + X\beta_2, \sigma_2\right)\ if\ X > V_c$$

Methodology

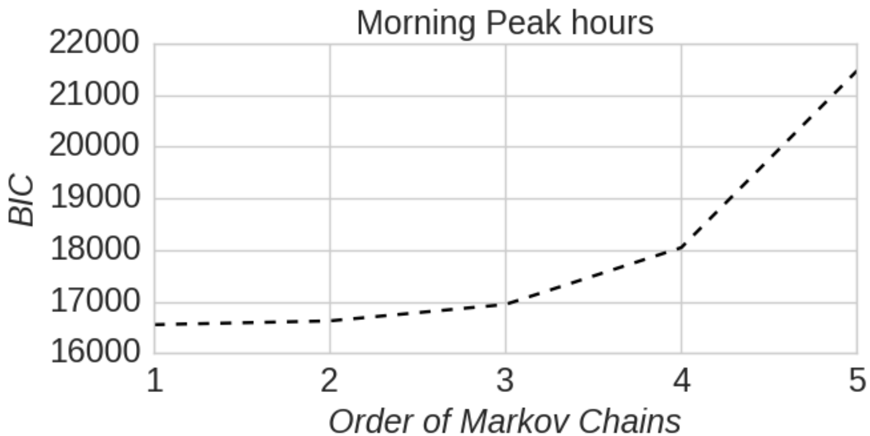
Investigation of the Markov Chains Order

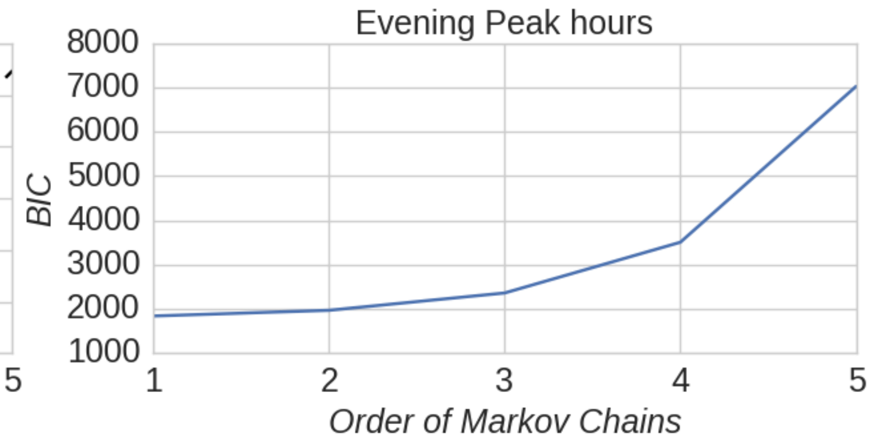
- Order of the Markov Chains was investigated using the Bayesian Information Criterion (BIC) approach

- The approach penalizes higher order models to balances the model complexity and the predictive accuracy to avoid the overfitting problem

$$BIC = -2 * ln(L) + (|S|^m - |S|^\ell)(|S| - 1) * ln(n)$$

Methodology



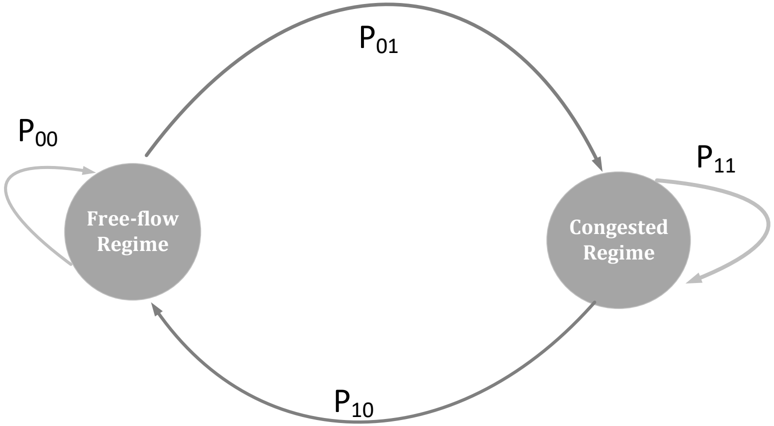


- The BIC approach favors lower order compared to higher order Markov Chains models

Methodology

Random Variation Markov Structured Model

- Discrete-time first-order Markov Chains models were developed for both the evening and the morning peak periods



❖ The transition processes can be presented in the matrix format below;

$$P_{ij} = \begin{pmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{pmatrix}$$

Methodology

Random Variation Markov Structured Model

$$P_{ij} = \begin{pmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{pmatrix}$$

$$P_{01} = Pr(Y_t = 1|Y_{t-1} = 0, X_{t-1} = x) = \Phi\left(\beta_0 + \ \beta X_{i,t-1}\right)$$

$$P_{11} = P(Y_t = 1)|Y_{t-1} = 1, X_{t-1} = x) = \Phi\left(\beta_0 + \ \beta X_{i,t-1}\right)$$

$$P_{00} = \ 1 - P_{01} \ and \ \ P_{11} = \ 1 - P_{10}$$

Methodology

Bayesian Parameter Estimations

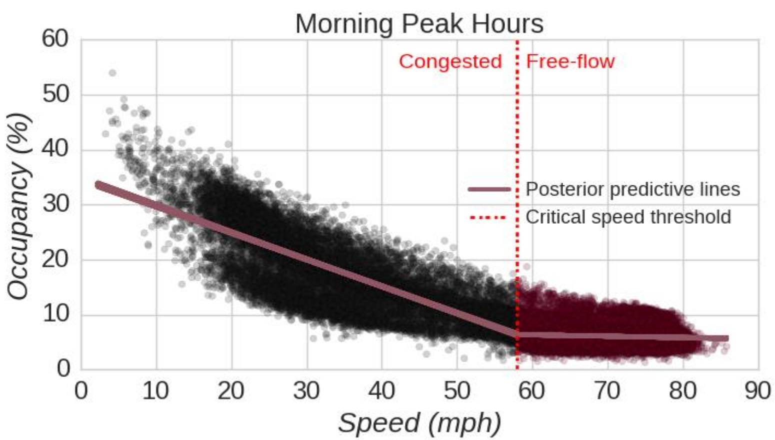
- The posterior distribution of the unknown parameters were estimated via the Markov Chain Monte Carlo simulations

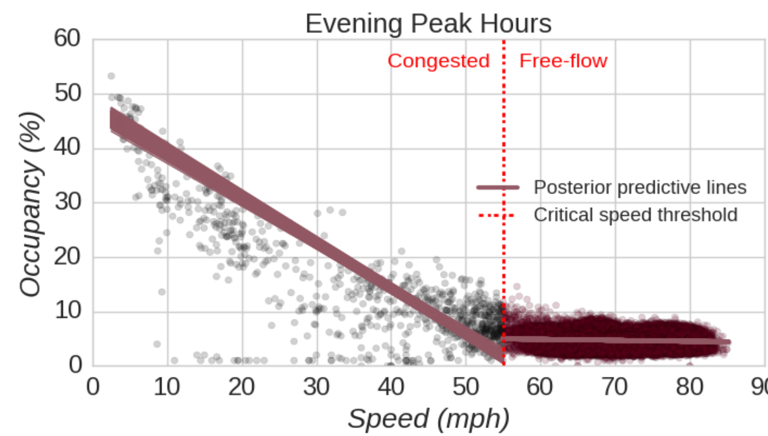
- Two chains of 20,000 iterations were run (first 10,000 as burn-in)

- Gelman-Rubin statistic was used to assess the convergence of chains

Results and Discussion

Bayesian change point regression model

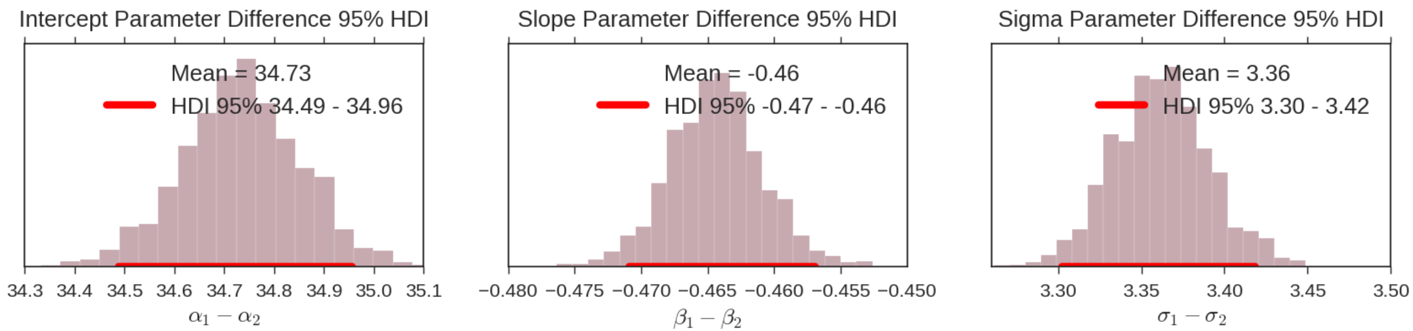




- Speed threshold during the morning and evening peak periods are 58 mph and 55 mph, respectively

Results and Discussion

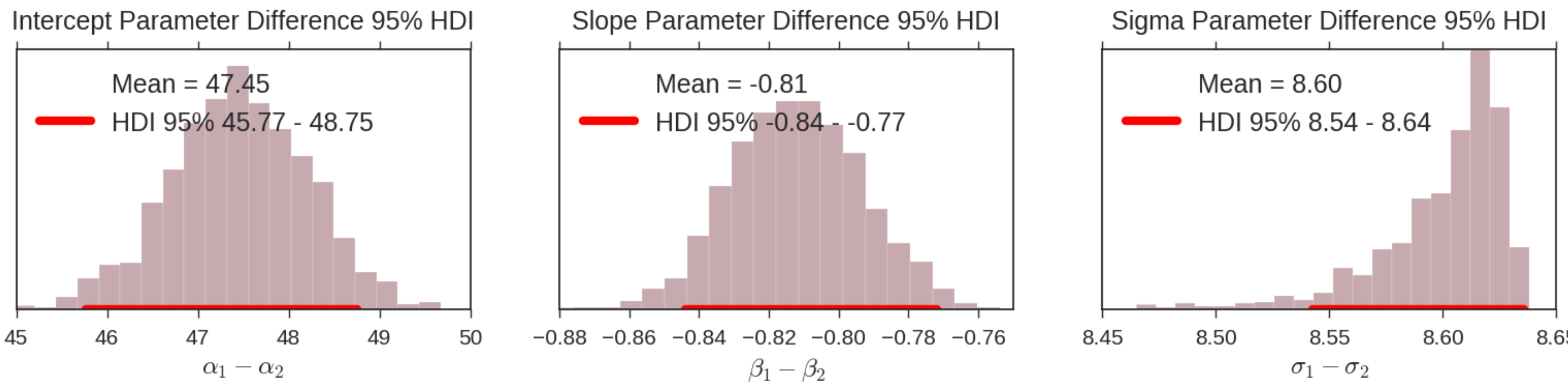
- The hypothesis test was conducted to verify if traffic patterns in the congested and free-flow regime are the same or credibly different.



Parameter posterior distributions differences for the morning peak period

- There is a statistically significant difference between the regression in free-flow and congested regime at 95% HDI

Results and Discussion



Parameter posterior distributions differences for the evening peak period

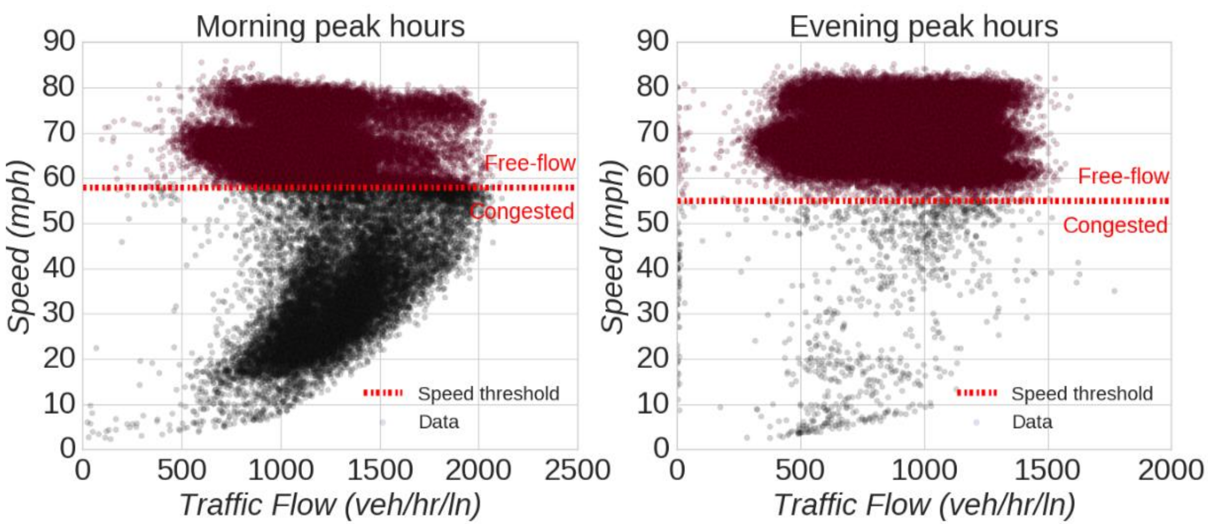
- There is a statistically significant difference between the regression in free-flow and congested regime at 95% HDI

Results and Discussion

Variable	Posterior Mean	Posterior Std.	95% Credible Interval	
			lower	upper
Morning Peak Period				
Remaining in a congested regime				
Intercept	1.24	0.078	1.085	1.387
Flow rate (*veh/hr/lane*)	0.00016*	0.00006	0.00004	0.00028
Breakdown process				
Intercept	-3.794	0.063	-3.914	-3.669
Flow rate (*veh/hr/lane*)	0.00145*	0.00005	0.00136	0.00154
Evening Peak Period				
Remaining in a congested regime				
Intercept	2.066	0.197	1.688	2.464
Flow rate (*veh/hr/lane*)	-0.0001	0.00021	-0.00153	0.00006
Breakdown process				
Intercept	-2.761	0.003	-2.970	-2.537
Flow rate (*veh/hr/lane*)	-0.00021	0.00012	-0.00047	0.00001

- Traffic flow significantly influence the evolution process of traffic regime at 95% CI during the morning peak period
- For evening peak period, traffic flow was insignificant in influencing the evolution process of traffic regime at 95% CI

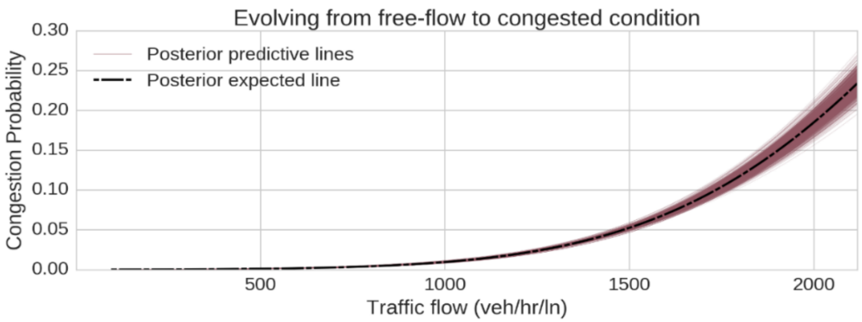
Results and Discussion

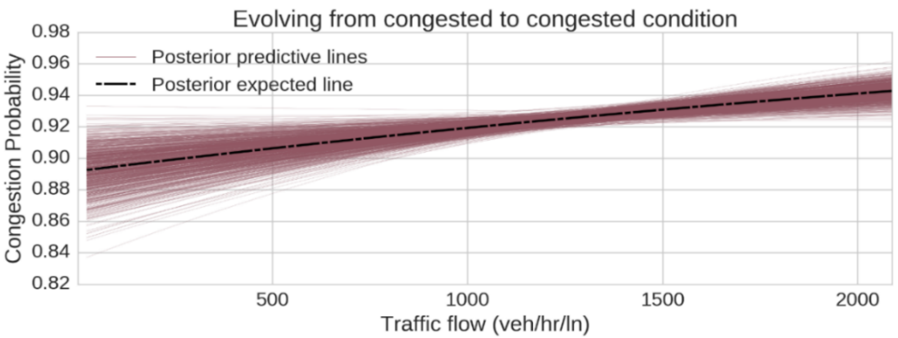


- For evening peak period, the insignificance of traffic flow may be associated with few sample data in the congested regime
- Highly scattered data characteristic below the speed threshold may have also contributed

Results and Discussion

Posterior predictive line of transition probability





- The probabilities of remaining in the congested state are higher than those of breakdown process at the same traffic flow

Conclusions

- The morning peak congested state occurs once speed is below 58 (mph) while the evening peak period occurs at a speed below 55 mph

- The Information Criterion favored that first-order Markov Chains assumption was sufficient to characterize the evolution of traffic congestion

- Results of Bayesian change point and Markov model can be useful to traffic operators and planners in managing recurring traffic congestion

Future Work

- Bayesian change point regression can be modified to account for more than two traffic regimes as congested, free-flow, congestion onset/dissipation

- Additional work is needed to evaluate the influence of spatial location, vehicle mix, and weather conditions on the evolution of traffic congestion

- It will be beneficial to test the proposed approaches in different locations and different types of bottlenecks

Thank you!