William W. Hay Railroad Engineering Seminar

Speaker #1 *"Shared-use Passenger Corridors in California: HSR and the Peninsula Corridor"*

Sam Levy - Massachusetts Institute of Technology

#2 *"Capacity Allocation in Vertically Integrated Railway Systems: A Sequential Bargaining Game Approach"*

Ahmadreza Talebian - University of Illinois at Chicago

Date: Friday, April 17, 2015
Time: Seminar Begins 12:20

Location: Newmark Lab, Yeh Center, Room 2311
University of Illinois at Urbana-Champaign

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Capacity Allocation in Vertically Integrated Railway Systems:

A Sequential Bargaining Game Approach with Focus on the US Context

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University of Illinois at Chicago

Hay Seminar
April 17, 2015

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Outline

- Background
- The model
  - Preprocessing
  - Bargaining game with complete information
  - Bargaining game with incomplete information
- Numerical analysis
- Concluding remarks

Background

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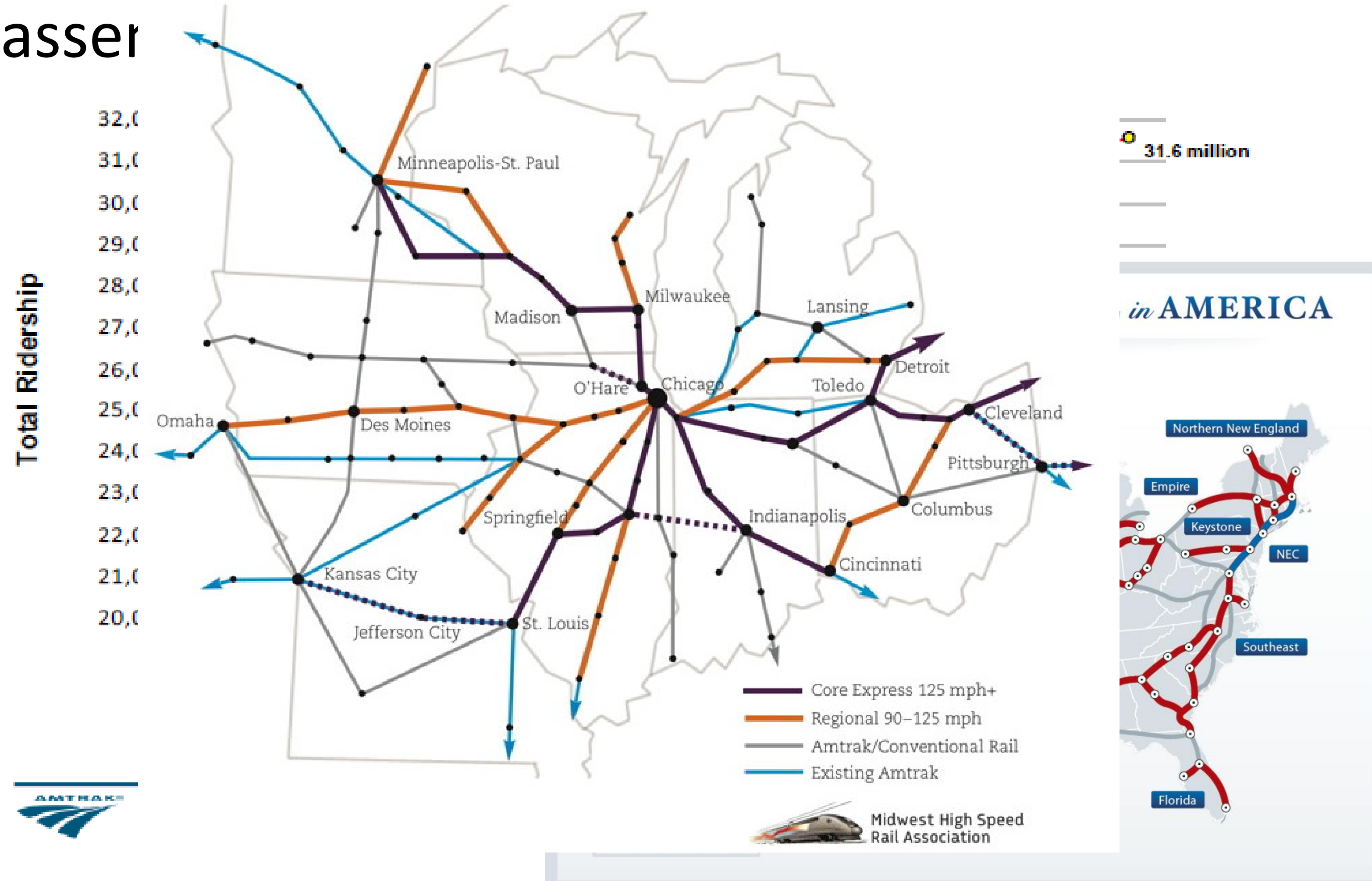
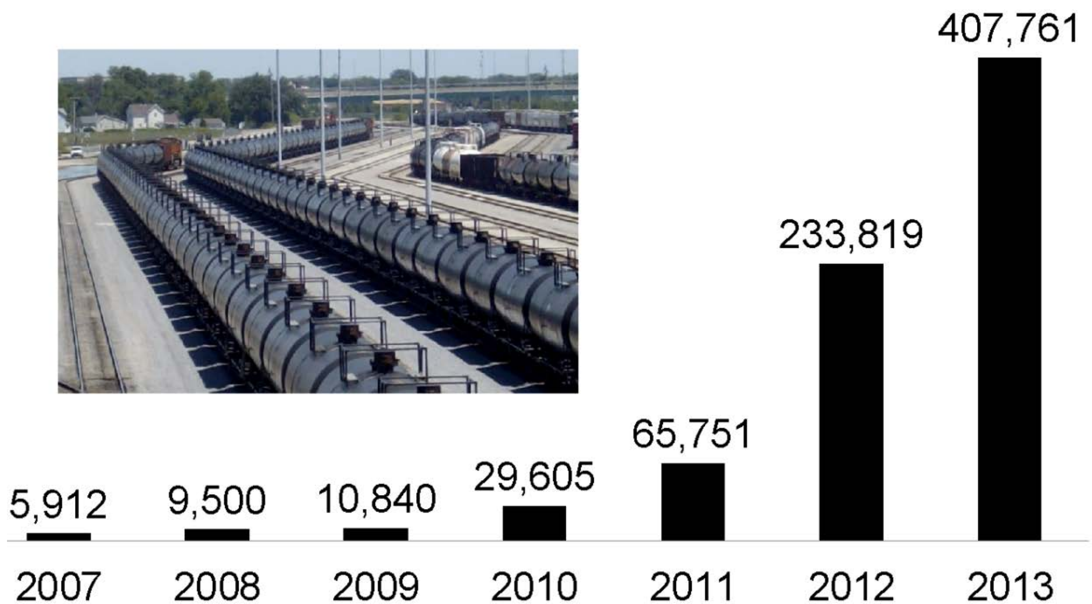


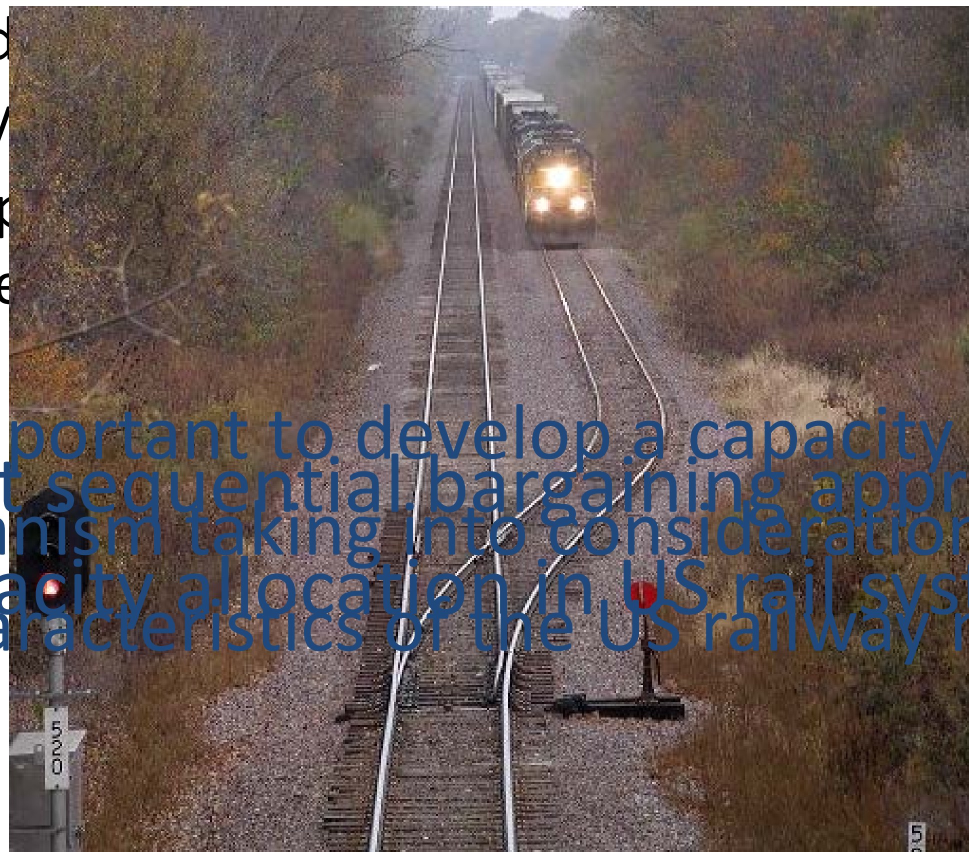
Background

- Freight side:
  - 15% increase in Class I Railroads' revenue ton-miles between 2001 and 2011
  - About 6800% increase in originated carloads of crude oil on Class I Railroads



Background

- Challenges of Higher Speed Rail lines
  - Single tracks with siding (meets and overpasses)
  - Shared ... mpacts on capacity
  - High sp... 0 mph (on-time ...



It is important to develop a capacity allocation mechanism taking into consideration different characteristics of the US railway market

The first sequential bargaining approach to capacity allocation in US rail system

The model

- Issues to be considered:
  - Complementary feature of rail tracks
  - Endogenous capacity
  - Amtrak's priority (Public Law 110-432)
  - Temporal variations in passenger demand
  - Train schedule inconvenience to passengers
  - Freight railroads keep their operating and financial information confidential

The model

- Preprocessing stage

    Module 1: Passenger delay components calculation

    Module 2: Freight train schedule generation

    Module 3: Establishing utility and cost values

- Equilibrium determination stage

    Module 4: Complete information gaming

    Module 5: Incomplete information gaming

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The model

Preprocessing stage

Module 1: Computing passenger delay components

- A set of feasible passenger train schedules is given
- Constant fare
- An initial schedule (the most preferred) and associated travel demand are given
- Delay components:
  - Schedule delay
  - En-route delay

The model

Preprocessing stage

Module 1: Computing passenger delay components

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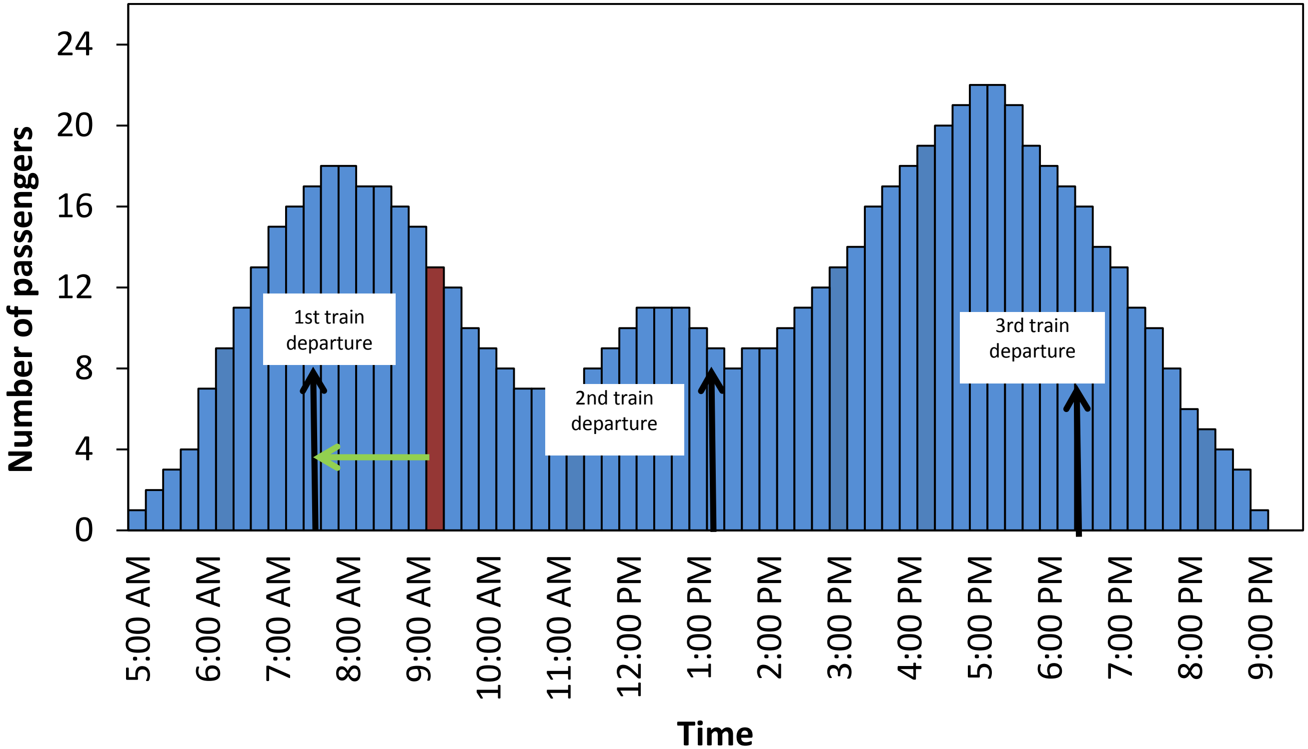

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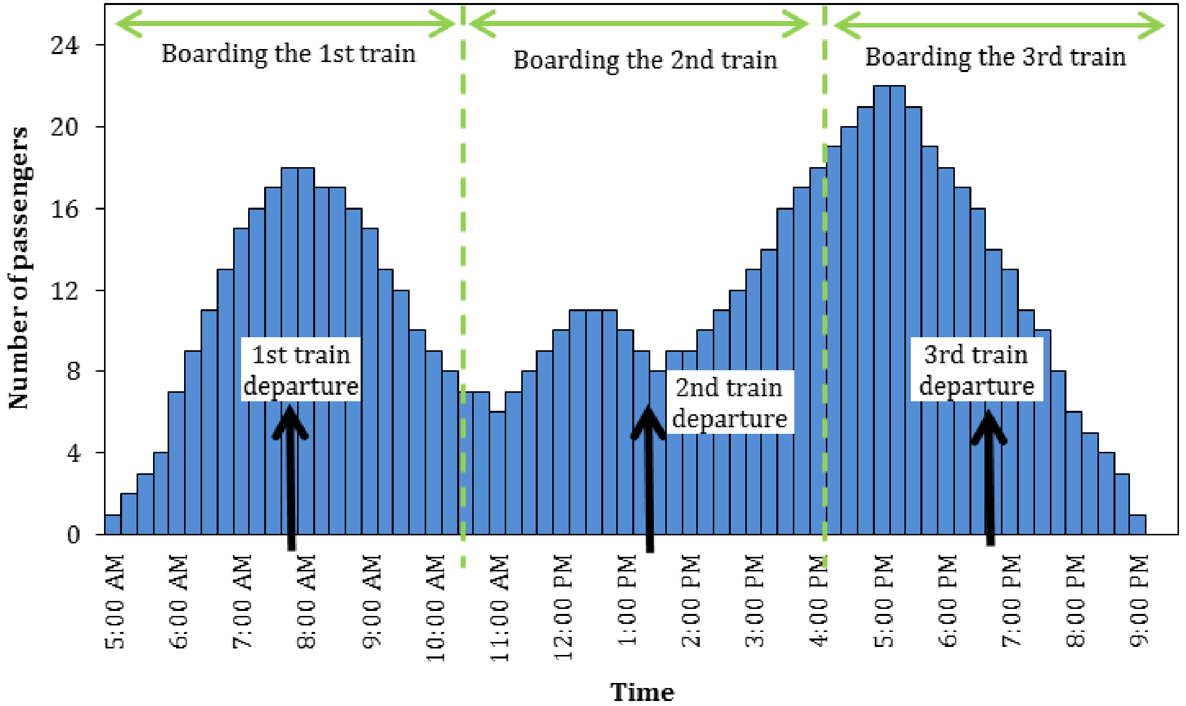
The model

Preprocessing stage

Module 1: Computing passenger delay components

- Each O-D pair has a passenger demand profile (Preferred Departure Time)
- Passengers are served by a predetermined number of trains



The model

Preprocessing stage

Module 1: Computing passenger delay components

- Passenger demand is elastic w.r.t. schedule delay
- Find the number of passengers departing the origin of station pair *w* at each time period *s*:

$$q_{s_i}^{w,m} = Q^{w,m}\left(1 - e_{d/w}\left(1 - \frac{S_{s_i}^{w,m}}{S_{int}^{w,m}}\right)\right)$$

The model

Preprocessing stage

Module 2: Solving the freight train scheduling problem

- Freight train scheduling is less precise and stringent in the US
- Freight trains are inserted among passenger trains (scheduling priority is granted to passenger trains)
- Minimize total freight side cost, which consists of foregone demand cost, train en-route delay cost, and train departure delay cost

Talebian, A., Zou, B., 2015. Train planning on a single track shared-use passenger and freight corridor with demand considerations: a focus on the US context. Submitted to Transportation Research Part B: Methodological.

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The model

Preprocessing stage

Module 3: Establishing utility and cost values

$U_{passenger}$ = operator revenue – (passenger schedule delay cost + operating cost of stopping status + passenger en-route delay cost)

$C_{freight}$ =Lost demand cost + track maintenance cost + departure delay cost + en-route delay cost + operating cost

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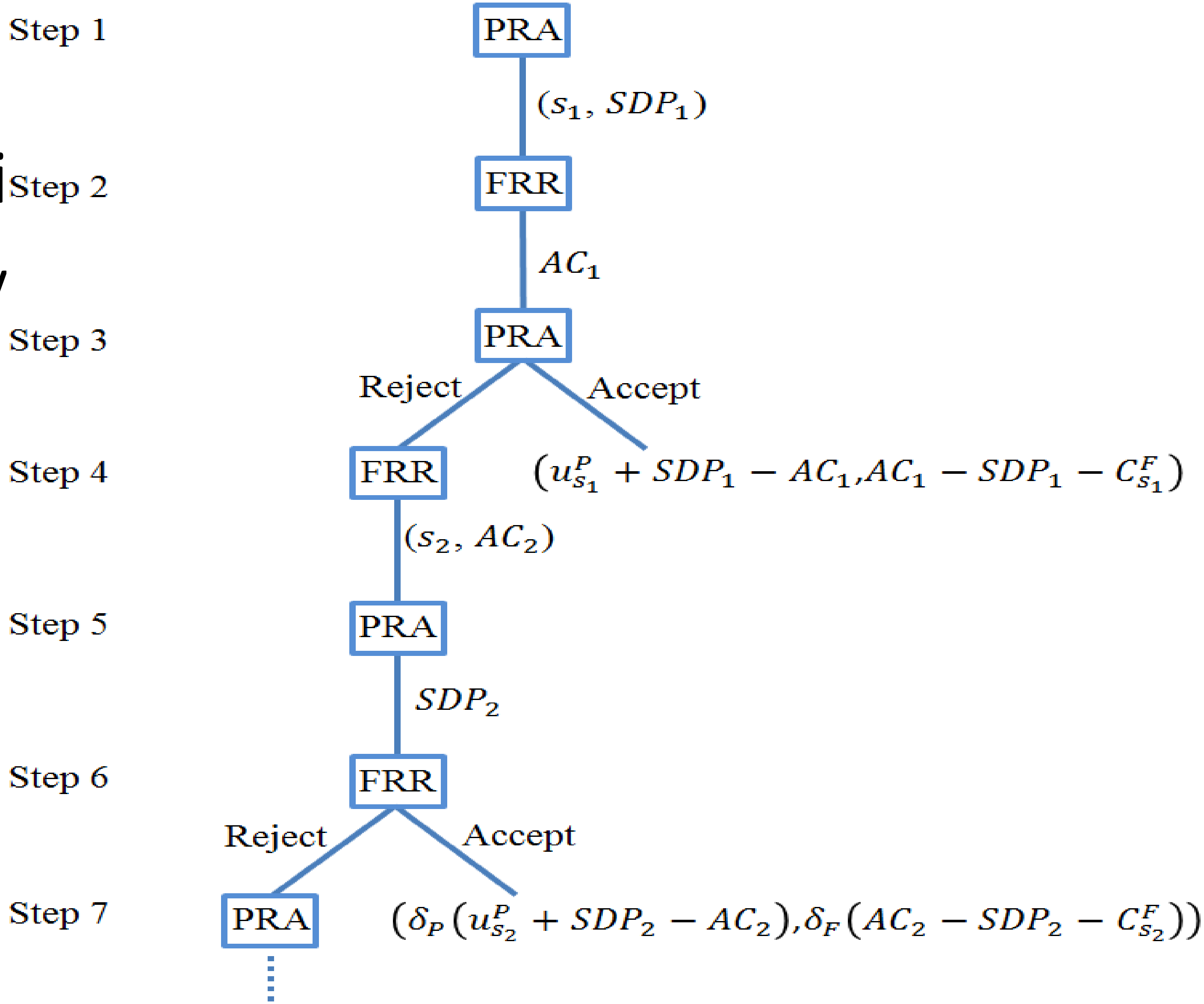
Step 1
PRA
(s_1, SDP_1)
Step 2
FRR
AC_1
Step 3
PRA
Reject
Accept
Step 4
FRR
$(u^P_{s_1} + SDP_1 - AC_1, AC_1 - SDP_1 - C^F_{s_1})$
(s_2, AC_2)
Step 5
PRA
SDP_2
Step 6
FRR
Reject
Accept
Step 7
PRA
$(\delta_P(u^P_{s_2} + SDP_2 - AC_2), \delta_F(AC_2 - SDP_2 - C^F_{s_2}))$

The model

Equilibrium determination

Solving complete information bargaining game

- Stationary structure of the game is employed to solve the game
- Equilibrium: *a schedule maximizing the PRA's utility minus FRR's cost (independent of the player initiating the game)*

- Net transfer from FRR to PRA:

$$SDP_1 - AC_1 = \frac{1}{1-\delta_F\delta_P}\left((1-\delta_P)u_{S^*}^P + (\delta_P - \delta_F\delta_P)C_{S^*}^F\right)$$

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The model

Equilibrium determination

Solving incomplete information bargaining game

- Class I freight railroads consider their operating and financial information highly critical to profitability and thus confidential

- A simplification: two-level bargaining
  - Upper level: price bargaining for each passenger train schedule
  - Lower level: schedule bargaining given the price for each schedule

The model

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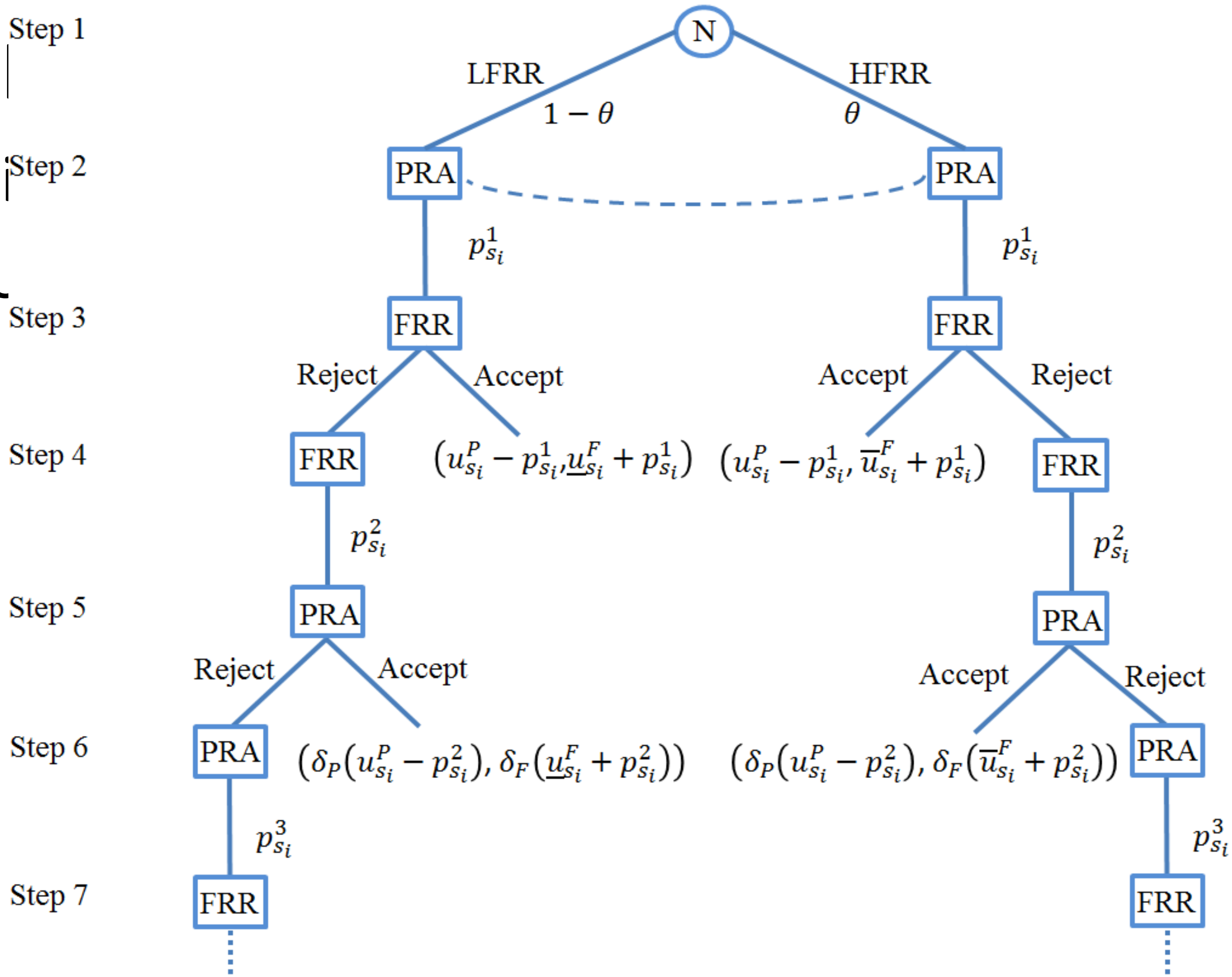

The model

Equilibrium determination

Solving incomplete information bargaining game

- Upper-level: price bargaining

$$p_{s_i}^{1*} = \begin{cases} \frac{1}{1-\delta_F\delta_P}\left((\delta_F-\delta_F\delta_P)u_{s_i}^P+(1-\delta_F)\overline{C}_{s_i}^F\right) & \theta>\hat{\theta} \\ \frac{1}{1-\delta_F\delta_P}\left((\delta_F-\delta_F\delta_P)u_{s_i}^P+(\delta_F\delta_P-\delta_F^2\delta_P)\overline{C}_{s_i}^F+\underline{C}_{s_i}^F(1-\delta_F-\delta_F\delta_P+\delta_F^2\delta_P)\right) & \theta\le\hat{\theta} \end{cases}$$

where

$$\hat{\theta} = \frac{\left(\overline{C}_{s_i}^F-\underline{C}_{s_i}^F\right)(1-\delta_F\delta_P)}{u_{s_i}^P-\underline{C}_{s_i}^F(1-\delta_F\delta_P)-\overline{C}_{s_i}^F(\delta_F\delta_P)}$$

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The model

Equilibrium determination

Solving incomplete information bargaining game

- Lower-level: schedule bargaining
  - Given the price of each schedule, PRA and FRR bargain to determine an equilibrium schedule
  - The schedule bargaining is a game with complete information as the price of each schedule is already determined

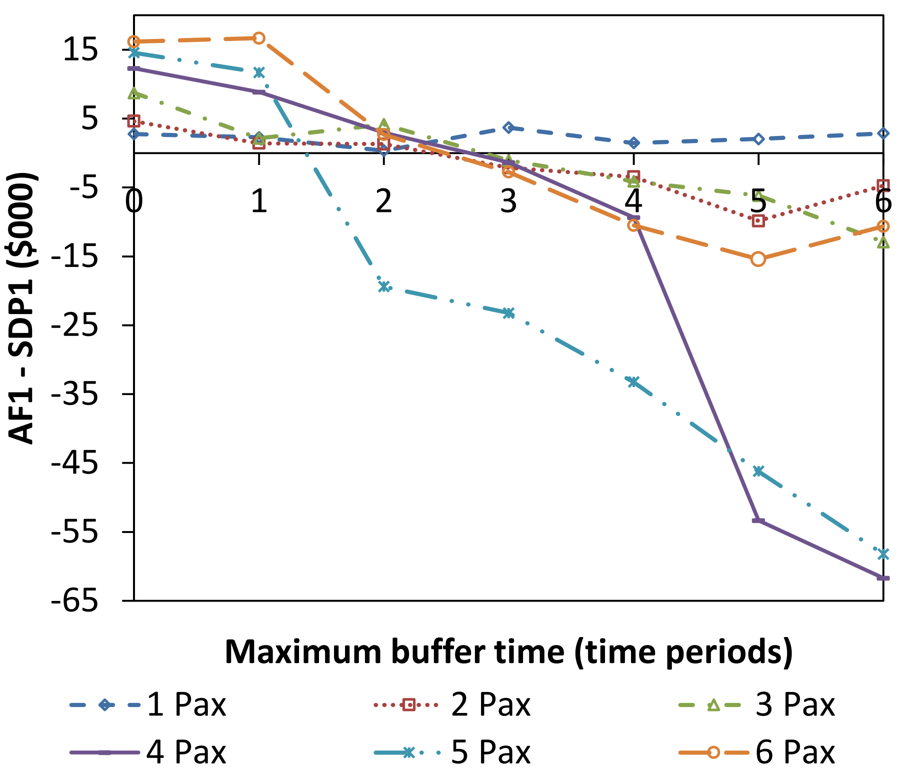
Numerical analysis

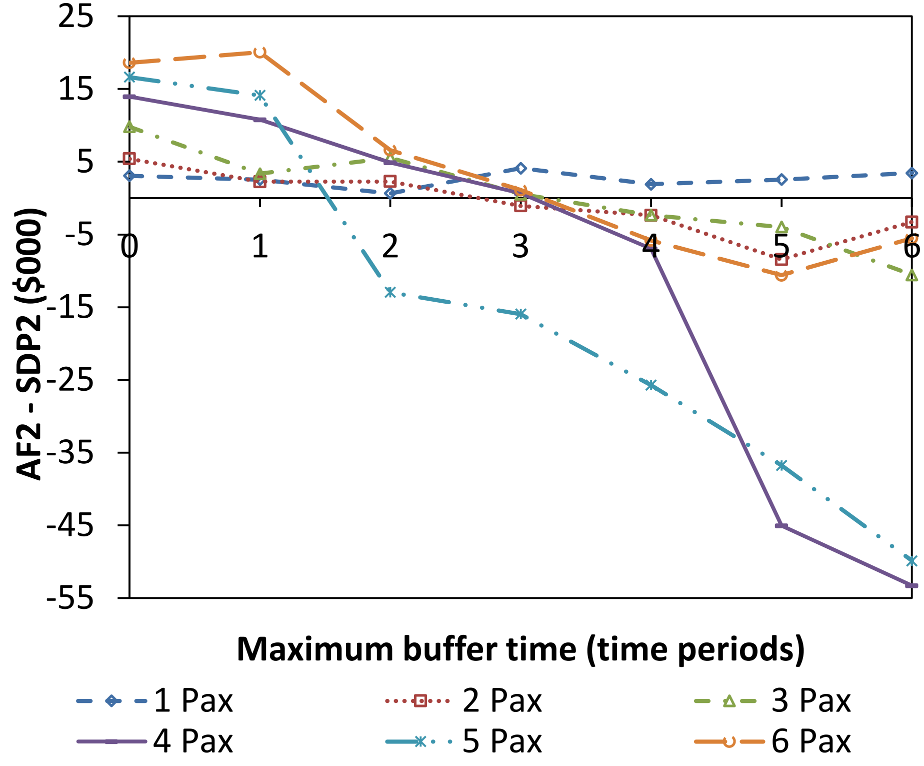
- Set up:
  - 11 blocks: 6 track segments and 5 sidings
  - 2 O-D pairs (one in each direction)
  - Each track segment 18 miles long
  - Sidings evenly distributed along the corridor, each 2 miles long
  - Total corridor length: 120 miles
  - Operating speed
    - Freight trains: 60 mph
    - Passenger trains: 120 mph

Numerical analysis

- Set up (cont'd)
  - Consider daily service frequency of 1-6 trains
  - Elastic passenger demand (elasticity: 0.4, based on Adler et al. (2010))
  - Parameter values are obtained from the literature
  - $\delta_P = 0.9, \delta_F = 0.85$

Numerical analysis





- Net internal transfers is greater if FRR initiates the game
- Net internal transfer could be negative (FRR should pay to PRA)

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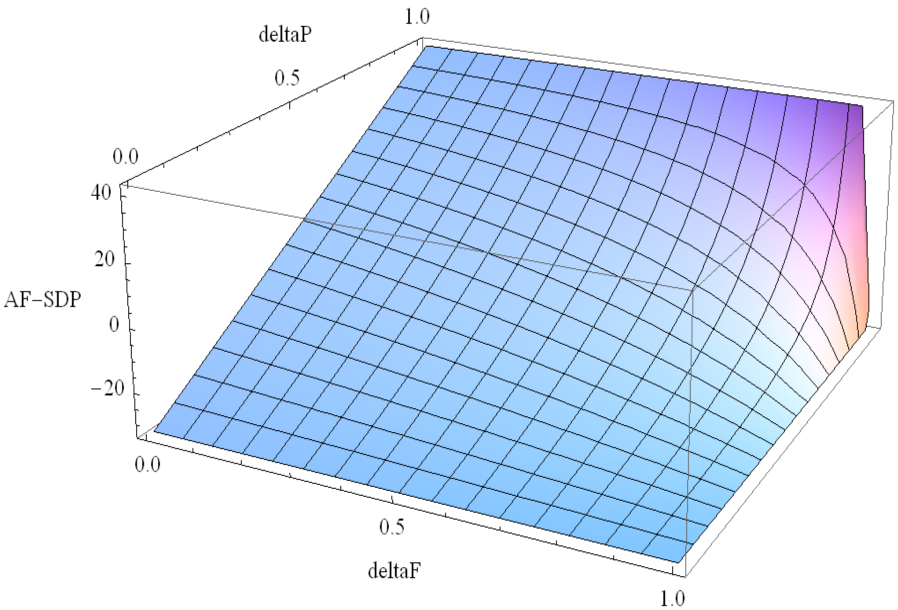
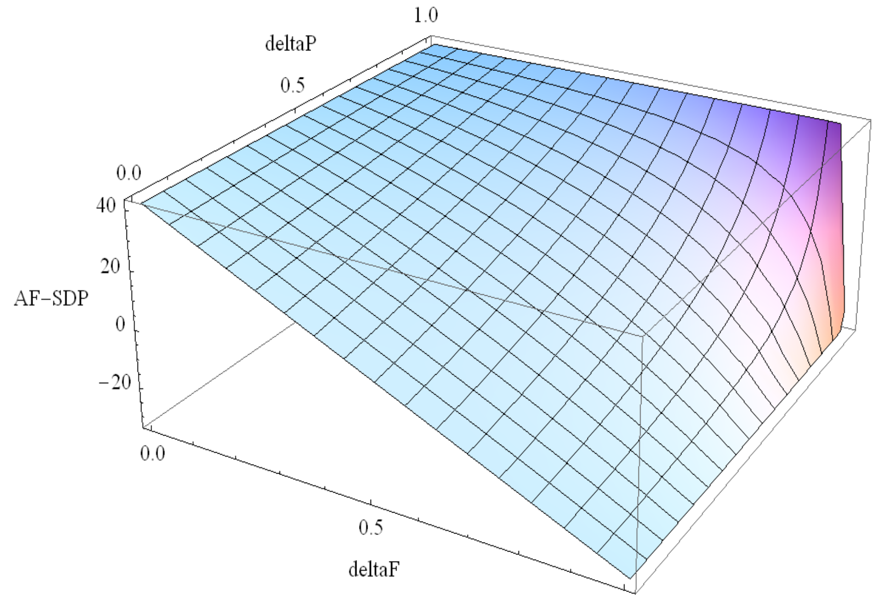
Numerical analysis



PRA initiates the game



FRR initiates the game

- Discount factors significantly impact the net internal transfer between agents

Concluding remarks

- Proposed the first sequential bargaining game model to identify capacity shares and associated charges on shared use rail corridors in the US context
- Bargaining game with complete information:
  - A schedule maximizing the utility of the passenger rail agency minus the cost of the freight railroad is the equilibrium solution
  - The equilibrium schedule is independent of the player initiating the game
- Two-level price and schedule bargaining extension for incomplete information
- On-going research: numerical analysis

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Thank you!

Questions and comments

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