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


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Location: Newmark Lab, Yeh Center, Room 2311  
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Hay Seminar
April 17, 2015
Outline

• Background

• The model
  – Preprocessing
  – Bargaining game with complete information
  – Bargaining game with incomplete information

• Numerical analysis

• Concluding remarks
Background

• Passenger rail resurgence in the US
• High performance rail systems (HSR and HRcR services)
• Midwest: existing single track lines are being upgraded to accommodate trains running at a maximum speed of 110 mph
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 passenger and freight use (negative impacts on capacity utilization)
  - High speed trains operating at 110 mph (on-time performance is essential)

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

- **Schedule delay**: The difference between one's desired departure time and the actual departure time.

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![Graph showing passenger delay components]

- **1st train departure**
- **2nd train departure**
- **3rd train departure**

Time

Number of passengers
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 $s$:

\[
q_{s_i}^{w,m} = Q^{w,m} \left( 1 - e^{-d/w} \left( 1 - \frac{s_{s_i}^{w,m}}{S^{w,m}_{int}} \right) \right)
\]
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

The model

Preprocessing stage

Module 3: Establishing utility and cost values

\[ U_{\text{passenger}} = \text{operator revenue} - (\text{passenger schedule delay cost} \]
\[ + \text{operating cost of stopping status} + \text{passenger en-route delay cost}) \]

\[ C_{\text{freight}} = \text{Lost demand cost} + \text{track maintenance cost} + \]
\[ \text{departure delay cost} + \text{en-route delay cost} + \text{operating cost} \]
Solving the Rubinstein sequential bargaining game

Equilibrium determination

Step 1

PRA

\((s_1, SDP_1)\)

Step 2

FRR

\(AC_1\)

Step 3

PRA

Reject

Accept

Step 4

FRR

\((u_{s_1}^P + SDP_1 - AC_1, AC_1 - SDP_1 - C_{s_1}^F)\)

\((s_2, AC_2)\)

Step 5

PRA

\(SDP_2\)

Step 6

FRR

Reject

Accept

Step 7

PRA

\((\delta_P(u_{s_2}^P + SDP_2 - AC_2), \delta_F(AC_2 - SDP_2 - C_{s_2}^F))\)

\(\ldots\)
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:
  \[ SDP_1 - AC_1 = \frac{1}{1 - \delta_F \delta_P} \left( (1 - \delta_P)u^P_s + (\delta_P - \delta_F \delta_P)C^F_s \right) \]
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

Equilibrium determination

- Step 1
- Step 2
- Step 3
- Step 4
- Step 5
- Step 6
- Step 7

Solving incomplete information bargaining game

Upper-level: price bargaining

There exist two types for FRR: low-cost FRR (LFRR) and high-cost FRR (HFF)

We conjecture two equilibria for the game (only one equilibrium will occur depending on \(\theta\) value)

PRA's prior belief: probability of HFRR is \(\theta\)
The model

Equilibrium determination

Solving incomplete information bargaining game

• Upper-level: price bargaining

\[ p_{s_i}^{1*} = \begin{cases} 
\frac{1}{1 - \delta_F \delta_P} \left( (\delta_F - \delta_F \delta_P) u_{s_i}^P + (1 - \delta_F) \overline{C}^F_{s_i} \right) & \theta > \hat{\theta} \\
\frac{1}{1 - \delta_F \delta_P} \left( (\delta_F - \delta_F \delta_P) u_{s_i}^P + (\delta_F \delta_P - \delta_F^2 \delta_P) \overline{C}^F_{s_i} + \overline{C}^F_{s_i} (1 - \delta_F - \delta_F \delta_P + \delta_F^2 \delta_P) \right) & \theta \leq \hat{\theta} 
\end{cases} \]

where

\[ \hat{\theta} = \frac{(\overline{C}^F_{s_i} - \overline{C}^F_{s_i}) (1 - \delta_F \delta_P)}{u_{s_i}^P - \overline{C}^F_{s_i}(1 - \delta_F \delta_P) - \overline{C}^F_{s_i}(\delta_F \delta_P)} \]
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
  – $\delta_P = 0.9, \delta_F = 0.85$
• Net internal transfers is greater if FRR initiates the game
• Net internal transfer could be negative (FRR should pay to PRA)
Numerical analysis

- 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.
Thank you!

Questions and comments

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