Optimal Grade Crossing Project Selection for Improved Running Time on Passenger Rail Corridors

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Demand for Passenger Service Upgrades

- New Amtrak ridership record 10 of past 11 years… 31.6 million in FY13
- Amtrak ridership is growing faster than any major travel mode
- Continued interest in increasing the frequency and speed of intercity passenger rail service on shared rail corridors
- Increase passenger trains speed and frequency at grade crossings
- Passenger rail corridor development must be supported by investment in grade crossing infrastructure
Track Speed and Grade Crossing Upgrades

- 40 mph: Passive (~$1,000)
- 60 mph: Active (~$100,000)
- 80 mph: Quad gates (~$1,000,000)
- 90 mph: Impenetrable Barrier (~$10,000,000)
- 110 mph: >125 mph: Grade Separation

Track speed categories and their corresponding crossing upgrade costs.
Passenger rail corridor involves a series of integrated systems.
“Go Fast by Not Going Slow…”

- Class 1: 240 seconds
- Class 2: 120 seconds
- Class 3: 60 seconds
- Class 4: 45 seconds
- Class 5: 40 seconds
- Class 6: 33 seconds
- Class 7: 29 seconds
- Class 8: 23 seconds
- Class 9: 18 seconds

Time per Mile (seconds) vs. Speed (MPH)
Ultimate Project Selection

- Corridor Investments
- Costs
- Planning Horizon
- Discount Rate
- Net Present Value
- Budget
- Service Targets

Transportation Utility

- Run Time
- Reliability
- Frequency

Passenger Demand → Ridership → Revenue

Net Present Value
Present Model Scope

- Run Time
- Transportation Utility
  - Reliability
  - Frequency
- Corridor Investments
- Costs
- Planning Horizon
- Discount Rate
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Flow:
- Passenger Demand → Ridership → Revenue → Net Present Value → Budget
- Planning Horizon → Discount Rate → Planning Horizon
- Corridor Investments → Costs
Project Benefits Depend on Boundary Conditions

![Graph showing speed 'A' and speed 'B' with segments 1, 2, and 3 labeled.](image)
Opportunities to Reduce Running Time

- Improvements can be made to address schedule minimum run time and schedule reliability
- Improvement projects have different impacts on both schedule components

**Schedule minimum run time**
- Infrastructure
  - Track structure
  - Track geometry
  - Signals
  - Grade crossings
- Rolling stock
  - Acceleration
  - Top speed
  - Curving performance

**Schedule reliability (uncertainty)**
- Single vs. double track
- Siding length and spacing
- Capacity utilization
  - Existing capacity
  - Other rail traffic
- Station dwell
- Passenger delays
**Model Objective Function**

Minimize Total Running Time:

\[
\sum_{n=1}^{N} \sum_{s=0}^{S} \sum_{t=1}^{T} \theta_{n,t} l_n \delta_s v_{n,s,s^*,t} + \sum_{n=2}^{N} \sum_{s=0}^{S} \sum_{s^*=0}^{S} \sum_{t=1}^{T} \theta_{n,t} \tau_{s,s^*,t} z_{n,s,s^*,t}
\]

- Segments
- Trains
- Speeds
- Segment length
- Segment specific train time weight factor
- Unit running time at speed ‘s’
- Segment train speed (1,0)
- Acceleration/Braking Delay
- ABD link variable (1,0)
### Model Constraints (1 of 2)

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \sum_{n=1}^{N} \sum_{c=0}^{C} x_{n,c} p_{n,c} \leq B ]</td>
<td>Budget constraint</td>
</tr>
<tr>
<td>[ \sum_{s=0}^{S} v_{n,s,t} \sigma_s \leq \sum_{c=0}^{C} x_{n,c} v_c ]</td>
<td>Train speed &lt; infrastructure speed</td>
</tr>
<tr>
<td>[ z_{n,s,s^<em>,t} \leq v_{n,s^</em>,t} ] (\forall n, s, s^*, t)</td>
<td>Acceleration and braking link (1)</td>
</tr>
<tr>
<td>[ z_{n,s,s^<em>,t} \leq v_{n-1,s,t} ] (\forall n, s, s^</em>, t)</td>
<td>Acceleration and braking link (2)</td>
</tr>
<tr>
<td>[ z_{n,s,s^<em>,t} + 1 \geq v_{n,s^</em>,t} + v_{n-1,s,t} ] (\forall n, s, s^*, t)</td>
<td>Acceleration and braking link (3)</td>
</tr>
<tr>
<td>[ l_n - a_{n,t} - b_{n+1,t} \geq 0 ] (\forall n, t)</td>
<td>Segment acceleration and braking dist.</td>
</tr>
</tbody>
</table>
### Model Constraints (2 of 2)

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b_{n,t} \geq \sum_{s=0}^{S} v_{n-1,s,t} \beta_{s,t} - v_{n,s,t} \beta_{s,t} \quad \forall \ 2 \leq n \leq N, t )</td>
<td>Braking distance</td>
<td>(8)</td>
</tr>
<tr>
<td>( a_{n,t} \geq \sum_{s=0}^{S} v_{n,s,t} \alpha_{s,t} - v_{n-1,s,t} \alpha_{s,t} \quad \forall \ 2 \leq n \leq N, t )</td>
<td>Acceleration distance</td>
<td>(9)</td>
</tr>
<tr>
<td>( \sum_{s=0}^{S} v_{n,s,t} \sigma_s \leq h_{n,t} \quad \forall \ n, t )</td>
<td>Station stopping constraint</td>
<td>(10)</td>
</tr>
<tr>
<td>( \sum_{s=0}^{S} v_{n,s,t} = 1 \quad \forall \ n, t )</td>
<td>One operating speed per service on each segment</td>
<td>(11)</td>
</tr>
<tr>
<td>( \sum_{c=0}^{C} x_{n,c} = 1 \quad \forall \ n )</td>
<td>One track maximum speed on each segment</td>
<td>(12)</td>
</tr>
</tbody>
</table>
Train Performance Calculator Constraints

\[ Z_{n,s,s^*,t} \leq v_{n,s^*,t} \quad \forall \ n, s, s^*, t \]  
\[ Z_{n,s,s^*,t} \leq v_{n-1,s,t} \quad \forall \ n, s, s^*, t \]  
\[ Z_{n,s,s^*,t} + 1 \geq v_{n,s^*,t} + v_{n-1,s,t} \quad \forall \ n, s, s^*, t \]
Minimum Upgrade Length Constraints

\[ L_2 - a_2 - b_3 \geq 0 \]

\[ L_2 - a_2 - b_3 < 0 \]
Case Study – Porter, IN to St. Joseph, MI

- One round trip frequency per day
- Route length of 176 mi
- 79 MPH maximum speed
- 44 MPH average speed (good case for improvement)
- Annual ridership 106,662 (FY ‘11)
- Selected segment from Porter to St. Joseph for current PSM case study
- Added hypothetical commuter rail service to demonstrate functionality of model
## Upgrade Treatments

<table>
<thead>
<tr>
<th>Track Class</th>
<th>Maximum Train Speed (MPH)</th>
<th>Track Structure</th>
<th>Signal System</th>
<th>Grade crossings / Misc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 3</td>
<td>60</td>
<td>Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing</td>
<td></td>
<td>Curve shift</td>
</tr>
<tr>
<td>Class 4</td>
<td>80</td>
<td>Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing</td>
<td>CTC</td>
<td>Curve shift</td>
</tr>
<tr>
<td>Class 5</td>
<td>90</td>
<td>Replace 1/3 Cross Ties (wood), 136RE CWR, Surfacing</td>
<td>CTC/AT S/ATC</td>
<td>Curve shift, Four quad gate crossings</td>
</tr>
<tr>
<td>Class 6</td>
<td>110</td>
<td>Replace 2/3 Cross Ties (wood), 136RE CWR, Surfacing</td>
<td>CTC/AT S/ATC</td>
<td>Curve shift, four quad gate crossings with intrusion detection, fenced ROW</td>
</tr>
</tbody>
</table>
Case Study Input Parameters

- Capital costs from Quandel Consultants (2011)
- Discount rate 5%, 10 year period
- Equal train running time weights (alpha 1 = alpha 2)
- Identical train consists for each service (1 loco, 6 coach, 1 NPCU*)
- Acceleration and braking performance from simplified TPC

Solution
- Mixed Integer Program (MIP) with GUROBI 5.0 solver
- 1-2 minutes to optimal solution for each scenario

* NPCU = Non-Powered Cab Unit
Initial vs. Final Condition ($45M)
Service Speeds ($45M)

Maximum  Express  Commuter

Distance (mi.)

Speed (MPH)
Change in Speed and Segment PV Cost ($45M)

- Change in Speed
- Cost

Improvement (MPH)

Distance (mi.)

Present Value Cost ($M)
Grade Crossing Improvements

- Improved crossings shown in orange
- Only a subset of crossings are improved corresponding to segments with speed improvement
- Crossings near speed restrictions and unimproved segments do not need to be upgraded, minimizing investment
Service Running Time vs. PV Cost

- Commuter Service
- Express Service

Running Time (min) vs. Present Value Cost ($M)
Running Time Reduction vs. PV Cost

- X-axis: Present Value Cost ($M)
- Y-axis: Running Time Reduction (min)
- Graph shows the relationship between running time reduction and present value cost.
Summary

• Grade crossings and protection devices are one part of the integrated passenger rail corridor system
• Can’t view in isolation due to interactions and train performance
• Requires a corridor approach to evaluate benefit of projects
• Optimization can prioritize and target investment for maximum return and suggest appropriate budgets for corridor upgrades
Thank you for your attention!

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