Topic #1 “Introducing Hybrid Optimization of Train Schedule (HOTS) Model as Timetable Management Technique”

Hamed Pouryousef
Michigan Technological University

Topic #2 “Hazards Associated with Shared-Use Rail Corridor Operations”

Chen-Yu Lin
University of Illinois at Urbana-Champaign

Date: Friday, April 03, 2015
Time: Seminar Begins 12:20
Location: Newmark Lab, Yeh Center, Room 2311
University of Illinois at Urbana-Champaign

Sponsored by

[RAILTEC Logo]

[NURail Center Logo]
Introducing Hybrid Optimization of Train Schedules (HOTS) Model as Timetable Management Technique

By: Hamed Pouryousef

Adviser: Dr. Pasi Lautala,

Michigan Tech. University
CEE Department
The U.S. railroads are looking for more efficient ways of using capacity, because of:

- Growing demand for passenger and freight services
- Limited capital to expand the infrastructure

Most challenges on **Shared-use Corridors**:

- Different types of trains (power, axle load, length, speed, and braking regimes)
- Different signaling and control systems (Generally)
Europe: long history for operating highly utilized shared-use corridors

The U.S.: growing interest to passenger-freight corridors

Network configuration and operation philosophy in the U.S. are different from Europe

Problem Statement:
Are there benefits on the U.S. shared-use corridors, (particularly passenger-oriented lines) from using “Operational Management Techniques”?
• **Timetable improvement** (rescheduling, rerouting) is one of the main “Operational Management” techniques to improve the capacity.

---

**Timetable & Capacity**

Amtrak.com, 2012
Timetable Compression Technique

• Recommended by UIC code 406 in European Practices.
• Modifies the pre-scheduled timetable and reschedules trains as close as possible to each other.
• No changes are allowed on the infrastructure or rolling stock specifications.

(a) Actual timetable for a quadruple-track corridor  
(b) compressed timetable with train order maintained  
(c) compressed timetable with optimized train order  
(Note: chart layout follows typical European presentation, and solid and dot lines represent different types of trains)  
(Landex, 2006)
Testing commercial software with operational management techniques to U.S. environment. Some challenges...

- Most with automatic train conflict resolution or timetable rescheduling/compression features......not both.

- Optimization features typically for either single track or double (multiple) track corridors under directional operation patterns.

- Hybrid simulation approach (combining “non-timetable” with “timetable” tools) time consuming and requires multiple commercial software

- No timetable compression model available in the U.S. rail network (similar to the RailSys compression algorithm for Europe)
Alternative Approach - HOTS

Hybrid Optimization of Train Schedules (HOTS)

Objective:

• A conflict-free rescheduling model capable for handling different types of rail corridors under both directional and non-directional operation approaches

Methodology:

• HOTS Model uses existing simulation software outputs and user-defined parameters to automatically improve the train schedules
HOTS Model, Main Steps

A) Simulation/TT Management Tools

B) Tabular Datasets (INPUT)

C) Optimization Part of HOTS Model

D) Tabular Datasets (OUTPUT)
HOTS Model Parameters, Variables, Objective

**User Defined Parameters**
- Level of Service
  - Min/Max Flexibility of Departure Times
  - Min/Max of Dwell Times
  - Hours of Daily Service
  - Model Coefficients

**User Defined + Simulation Parameters**
- Train Data
  - List of Trains
  - Priority
  - Headway
  - Defined Routes

**Simulation/TT Tool Parameters**
- Infrastructure Data
  - Siding/Yard/Crossovers
  - Main Lines/Tracks
- Operations Data
  - Origin/Destination
  - Requested Departure Times
  - Min Travel Times

**Optimization Part of “HOTS” Model**
Objective: To Compress Train Schedule
(Minimizing Train Departure Times + Deviation from Min. Dwell Times)

**Output**
- Adjusted Dwell Times
- Adjusted Departure Times

HOTS Model Input Categories/Sources and the Model Outputs/Objective
Battle between “TT Compression” & “Resolving Conflicts”

- Resolving the Conflicts
- Initial TT + Defined Criteria
- TT Compression Technique
Key Parameters of HOTS Model

**KEY Parameters:**

- Initial departure times
- Flexibility of departure times
- Min/Max of dwell times
- Train-routes
To minimize the deviation of dwell times (1) and departure times of trains (2), considering the importance weighting of dwell times and departure times.
Model Constraints (Same-Order Approach)

\[ XDT_t^i \geq DT_t^i - F1DT_t^i \]
\[ \forall t \in T, \forall i \in S \] (EQ. 1)

\[ XDT_t^i \leq DT_t^i + F2DT_t^i \]
\[ \forall t \in T, \forall i \in S \] (EQ. 2)

(EQ. 1 & 2) **Departure times** proposed by the model should be maintained between the earliest and latest possible departure time allowed for each train.

\[ LW_t^i \leq XW_t^i \leq UW_t^i \]
\[ \forall t \in T, \forall i \in S \] (EQ. 3)

(EQ. 3) **Dwell time** proposed by the model should be maintained between the min and max dwell times allowed for each train.
Model Constraints (Same-Order Approach)

\[ XDT^d_t - XDT^o_t = \sum_j \sum_i TR^{ij}_t + \sum_j XW^j_t \quad \forall t \in T, \forall i, j \in S, \ |i - j| = 1, \]
\[ d \in D_t, \ o \in O_t \]  (EQ. 4)

\[ XDT^i_t = XDT^i_t + TR^{ij}_t + XW^j_t \quad \forall t \in T, \forall i, j \in S, \ |i - j| = 1 \]  (EQ. 5)

\((EQ. 4 \& 5)\) guarantees that trains will not be lost in the model and each train follows the respective OD and routes, assigned in the model.
Model Constraints (Same-Order Approach)

\[ XDT_t^i - XDT_p^i \geq H(T_p) + H(T_t) + (TR_p^{ij} - TR_t^{ij}) \]

If \((U_t \times U_p = 1)\) AND \((DT_t^i > DT_p^i)\) AND \((TR_p^{ij} \geq TR_t^{ij})\) AND \((MR_p^{ij} = MR_t^{ij})\)

\[ \forall t, p \in T, t \neq p, \forall i, j \in S, |i - j| = 1 \]  \hspace{1cm} (EQ. 6)

\[ XDT_t^i - XDT_p^i \geq H(T_p) \hspace{2cm} \text{If} \ (U_t \times U_p = 1) \ \text{AND} \ (DT_t^i > DT_p^i) \]

\[ \text{AND} \ (TR_p^{ij} < TR_t^{ij}) \ \text{AND} \ (MR_p^{ij} = MR_t^{ij}) \ \forall t, p \in T, t \neq p, \forall i, j \in S, |i - j| = 1 \]  \hspace{1cm} (EQ. 7)

(EQ. 6&7) These two constraints resolve any potential conflicts between each two individual trains in the same direction.
**Model Constraints (Same-Order Approach)**

\[
XDT^i_t \geq XDT^j_p + TR^{ji}_p + H(T_p) \quad \text{If } (U_t \times U_p = -1) \text{ AND } (DT^i_t \geq DT^j_p) \\
\text{AND} (MR^{ji}_p = MR^{ij}_t), \quad \forall t, p \in T, t \neq p, \forall i, j \in S, |i - j| = 1
\]  
*(EQ. 8)*

**(EQ. 8)** Similar to Eq. 6 & 7, it resolves any potential conflicts between each two individual trains running in the **opposite directions**.

\[
XDT^d_t - XDT^o_p \leq SH \quad \forall t, p \in T, d \in D_t, o \in O_t
\]  
*(EQ. 9)*

**(EQ. 9)** The limitation of timetable duration.

\[
XDT^i_t \geq 0, \; XDT^i_t \in \text{integer}, \; XW^i_t \geq 0, \; XW^i_t \in \text{integer}
\]  
*(EQ. 10)*

**(EQ. 10)** Optimized departure times and suggested dwell times (variables) are positive integer values.
Model Constraints ("Order-Free" Approach)

- In "Order-Free" approach, trains depart based on the earliest possible departure times, as determined based on allowed flexibility parameter ($F_{1DT}$)
- Same objective and constraints similar to the "Same-Order" approach, except in:

\[
\begin{align*}
XDT_t^i & \geq XDT_p^i + H(T_p) + H(T_r) + (TR_p^j - TR_r^j) & \text{If} \ (U_t \times U_p = 1) \ \text{AND} \ (DT_t^i - F_{1DT}^i > DT_p^i - F_{1DT}^i) \\
(DT_t^i - F_{1DT}^i) & \text{AND} \ (TR_p^j \geq TR_r^j) \ \text{AND} \ (MR_p^j = MR_r^j) & \forall t, p \in T, t \neq p, \forall i, j \in S, \ |i - j| = 1
\end{align*}
\]

(6-a)

\[
\begin{align*}
XDT_t^i & \geq XDT_p^i + H(T_p) & \text{If} \ (U_t \times U_p = 1) \ \text{AND} \ (DT_t^i - F_{1DT}^i > DT_p^i - F_{1DT}^i) \\
& \text{AND} \ (TR_p^j < TR_r^j) \ \text{AND} \ (MR_p^j = MR_r^j) & \forall t, p \in T, t \neq p, \forall i, j \in S, \ |i - j| = 1
\end{align*}
\]

(7-a)

\[
\begin{align*}
XDT_t^i & \geq XDT_p^i + H(T_p) + TR_p^j & \text{If} \ (U_t \times U_p = -1) \ \text{AND} \ (DT_t^i - F_{1DT}^i > DT_p^i - F_{1DT}^i) \\
& \text{AND} \ (MR_p^j = MR_t^j) & \forall t, p \in T, t \neq p, \forall i, j \in S, \ |i - j| = 1
\end{align*}
\]
Testing the HOTS Model Applications

- Different scenarios were applied on single and multiple track case studies to test the performance of the model:
  - **Single Track Case Study**
    - 1-1- Improving an initial timetable with serious trains’ conflict
    - 1-2- Improving an initial “Conflict-Free” timetable
    - 1-3- Comparing the compression techniques between RailSys and HOTS model (two scenarios)
  - **Double/Multiple-track Case Study**
    - 2-1- Timetable compression through rescheduling
    - 2-2- Rescheduling timetable based on rerouting a train

- **HOTS Model Operation**
  - LINGO 14 (solver)
  - MS Excel (dataset)
  - Case studies considered “stand-alone corridors”
  - Rescheduling/rerouting restrictions based on user input
The initial timetable (a) with several schedule conflicts (three of them marked as example), improved timetables after the HOTS optimization, “Same-Order” (b) and “Order-Free” scenario (c).
The initial timetable developed in RTC with no manual improvement (a) was improved using “Same-Order” approach of the HOTS model (b)
Comparison between a compressed timetable by RailSys (b), and the outputs by HOTS model (c) (Different compression techniques)
The already compressed timetable by RailSys, (a) tested for further improvement by HOTS model (b). (Equal outcomes)
Summary of HOTS Model Results (Single Track)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Scenario 1-1</th>
<th>Scenario 1-2</th>
<th>Scenario 1-3</th>
<th>Scenario 1-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial TT*</td>
<td>Improved by HOTS</td>
<td>Initial TT*</td>
<td>Improved by HOTS</td>
</tr>
<tr>
<td>LOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of stops</td>
<td>23</td>
<td>14</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td>Min. dwell time</td>
<td>0’</td>
<td>0’</td>
<td>0’</td>
<td>0’</td>
</tr>
<tr>
<td>Max. dwell time</td>
<td>20’</td>
<td>61’</td>
<td>30’</td>
<td>10’</td>
</tr>
<tr>
<td>Total dwell times</td>
<td>132’</td>
<td>271’</td>
<td>166’</td>
<td>80’</td>
</tr>
<tr>
<td>Conflicts Removed</td>
<td>Several Conflicts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT* duration</td>
<td>5h 30’</td>
<td>6h 10’</td>
<td>5h 25’</td>
<td>7h 04’</td>
</tr>
<tr>
<td>TT* Compression (minutes / %)</td>
<td>-</td>
<td>-</td>
<td>45’</td>
<td>-</td>
</tr>
<tr>
<td>Conflicts Removed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Successful Compression</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparative Compression</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TT*: Timetable

**Conflicts Removed**

**Successful Compression**

**Comparative Compression (Different Compression Techniques)**
HOTS Test 2-1 – Rescheduling Scenario

Initial (a) and rescheduled timetable (b) of a multiple-track corridor based on “Same-Order” approach of HOTS Model
Previous timetable developed in Scenario 2-1 (a) was rescheduled by the HOTS model to address the new route defined for Train #2 (b)
## Summary of HOTS Model Results (Multiple Track)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Initial TT*</th>
<th>Rescheduled by HOTS (Scen. 2-1)</th>
<th>Rescheduled by HOTS Based on New Route (Scen. 2-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of stops</td>
<td>402</td>
<td>402</td>
<td>402</td>
</tr>
<tr>
<td>Min. dwell time</td>
<td>1’</td>
<td>1’</td>
<td>1’</td>
</tr>
<tr>
<td>Max. dwell time</td>
<td>3’</td>
<td>2’</td>
<td>2’</td>
</tr>
<tr>
<td>Total dwell times</td>
<td>557’</td>
<td>405’</td>
<td>405’</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT* duration</td>
<td>23h 46’</td>
<td>22h 58’</td>
<td>22h 58’</td>
</tr>
<tr>
<td>TT* Compression (Minutes, %)</td>
<td>-</td>
<td>48’</td>
<td>48’</td>
</tr>
<tr>
<td>(Minutes, %)</td>
<td>-</td>
<td>3.3%</td>
<td>3.3%</td>
</tr>
</tbody>
</table>

*TT*: Timetable

Successful Compression

Maintained the same LOS and TT duration, while resolving the conflicts after rerouting
Investigating Trade-off Trends between Capacity and LOS

Four different initial timetable selected out of the same single track case study, *(same number of trains, same infrastructure)*, but:
- Different stop patterns
- Different initial departure times

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Initial TT1</th>
<th>Initial TT2</th>
<th>Initial TT3</th>
<th>Initial TT4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of stops</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Max. dwell time</td>
<td>10’</td>
<td>0’</td>
<td>0’</td>
<td>61’</td>
</tr>
<tr>
<td>Total dwell times</td>
<td>80’</td>
<td>0’</td>
<td>0’</td>
<td>271’</td>
</tr>
<tr>
<td>Capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT* duration</td>
<td>7h 04’</td>
<td>6h 10’</td>
<td>5h 00’</td>
<td>6h 10’</td>
</tr>
</tbody>
</table>

*TT*: Timetable

Conflict-free Good LOS  Conflict Congested  Conflict Over Congested  Conflict-free Congested
Investigating Trade-off Trends between Capacity and LOS

Max. dwell time (min)
Number of stops
TT duration (min/10)
Total dwell times (min)

Max. dwell time (min)
Number of stops
TT duration (min/10)
Total dwell times (min)

Max. dwell time (min)
Number of stops
TT duration (min/10)
Total dwell times (min)

Max. dwell time (min)
Number of stops
TT duration (min/10)
Total dwell times (min)
Investigating Trade-off Trends between Capacity and LOS

Overall, Reverse Correlation between “Capacity Utilization and LOS”

Type of “Initial Timetable” is a key element.
Summary and Conclusions

• Different methodologies should be investigated/considered to address rail capacity issues
• Operational management methodologies provide an alternative when capital improvements not possible
  • Timetable compression shows potential for increased corridor utilization
  • Reduction of recovery time during unexpected events/delays is one drawback
• A new standalone model called “Hybrid Optimization of Train Schedule” (HOTS). Key highlights:
  • Analytical model to supplement commercial rail simulation
  • Applicable on various types of rail networks
  • Different parameters of rescheduling/compression techniques
  • Rescheduling /rerouting scenarios (Conflict-free)
  • Rescheduling under “Same-Order” or “Order-Free” approaches
• **HOTS Model** was successfully tested on different scenarios:
  • Conflict resolution
  • Improving and compressing the initial timetable
  • Despite differences in technique, similar compression results with RailSys
  • Demonstrated the trade-off between capacity utilization and LOS parameters on a single track case study

• Updates to remove/reduce current limitations:
  • **Station capacity limits**
    • New constraint
    • Update the station concept from “Node-based” to Link-based” pattern
  • **TT Compression to the right side** (concept of departing some trains “Later” instead of “Early” departure)
  • **More user-friendly interface/solver**
  • Model with “Stochastic” technique instead of “Deterministic” approach (freight trains)
  • **New applications:**
    • Public transit (subway, LRT, Commuter services)
    • Real-time rescheduling/rerouting application
Thanks for Your Attention!

Question or Comment?
hpouryou@mtu.edu

Acknowledgment:
Amtrak (Davis Dure)
Berkeley Simulation-RTC (Eric Wilson)
Lindo Systems, INC.- LINGO (Mark Wiley)
OpenTrack (Daniel Huerlimann)
RMCon GmbH- RailSys (Sonja Perkuhn, Gabriele Löber)
Michigan Tech. University (Jack Kleiber)

This research was supported by National University Rail (NURail) Center, a US DOT-OST Tier 1 University Transportation Center