046 Emergent Train Scheduling under Restricted Electrical Energy with Considering Trade-off between Energy Consumption and Trip Time

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1. Introduction
2. Countermeasures against Power Shortage
3. Optimization of Train Timetables
4. Simulation, a Case Study
5. Conclusion
Background

- Uncertain power supply in Japan by
  - East Japan Earthquake Disaster
  - Accident of the Fukushima Nuclear Power Station
- Influence on train operation
  - 15% reduction of energy
  - reduced number of trains
  - lack of robustness
- Need of countermeasures
  - studying them in advance
Energy Savings in Train Operation

- Eco-driving
  - optimization of train speed profiles for each interstation

- Eco-scheduling
  - optimization of distribution of slack times for every interstations
Objectives

- comparing some countermeasures of train timetabling against such power shortage quantitatively
  - by macroscopic simulation
- evaluation of schedule by
  - energy saving
  - passenger disutility
  - (peak power shaving)
  - need of microscopic simulation
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Four Major Countermeasures

**Strategy 0:** reduced number of cars per train

**Strategy 1:** curtailed train service

**Strategy 2:** reduced number of stops

**Strategy 3:** slow down
<table>
<thead>
<tr>
<th></th>
<th>strategy 0</th>
<th>strategy 1</th>
<th>strategy 2</th>
<th>strategy 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>reduced number of cars per train</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>peak power</td>
<td><strong>very good</strong></td>
<td>fair</td>
<td>fair</td>
<td>fair</td>
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<tr>
<td>energy</td>
<td><strong>very good</strong></td>
<td>good</td>
<td><strong>very good</strong></td>
<td><strong>very good</strong></td>
</tr>
<tr>
<td>car scheduling</td>
<td><em>bad</em></td>
<td>good</td>
<td><strong>very good</strong></td>
<td>fair</td>
</tr>
<tr>
<td>crew scheduling</td>
<td><strong>very good</strong></td>
<td>good</td>
<td><strong>very good</strong></td>
<td>fair</td>
</tr>
<tr>
<td>transport capacity</td>
<td>fair</td>
<td>fair</td>
<td><strong>very good</strong></td>
<td>good</td>
</tr>
<tr>
<td>passenger utility</td>
<td>good</td>
<td><em>bad</em></td>
<td>fair</td>
<td>fair</td>
</tr>
<tr>
<td>easiness of passenger guidance</td>
<td>good</td>
<td>good</td>
<td><strong>bad</strong></td>
<td>good</td>
</tr>
<tr>
<td>robustness against train delay</td>
<td>good</td>
<td>good</td>
<td>good</td>
<td>fair</td>
</tr>
</tbody>
</table>
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Energy-saving (Eco) Train Scheduling

- Total trip time $T_S$ is given as a constant.
- Runtime for $i$-th interstation $T_i$ is a variable.
  - by adjusting slack time
- The minimal energy consumption is solved by varying the $T_i$. 

![Diagram showing variables and constants]
Formulation with Nonlinear Programming

\[
J(T_1, \cdots, T_N) = \sum_{i=1}^{N} W_i(T_i) \rightarrow \min
\]

total energy consumption

subject to

\[
\sum_{i=1}^{N} T_i = T_S
\]

total trip time

Applying Lagrange multiplier technique

\[
L(T_1, \cdots, T_N, \lambda) = \sum_{i=1}^{N} W_i(T_i) + \lambda \left( \sum_{i=1}^{N} T_i - T_S \right)
\]

\[
\frac{\partial L}{\partial T_i} = \frac{\partial L}{\partial \lambda} = 0 \quad (i = 1, 2, \cdots, N)
\]
Derived Law

\[ \frac{\partial W_1}{\partial T_1} = \frac{\partial W_2}{\partial T_2} = \ldots = \frac{\partial W_N}{\partial T_N} = -\lambda \]

Law of Identical Incremental Energy Consumption

If incremental energy for all interstations are identical, the schedule is optimal.
Passenger Trip Times

- giving number of passengers for each Origin-Destination (OD) pair
- evaluating the following items
  - waiting time at a station assuming uniform passenger arrival
  - running time between O and D
  - (transfer time)
- sum of total times for all passengers
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Assumed Conditions

5 min. interval = 12 trains/hour

some trains passing

skipped stop

passenger demand per hour

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<td>A</td>
<td></td>
<td>–</td>
<td>600</td>
<td>900</td>
<td>1800</td>
<td>900</td>
<td>6000</td>
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<tr>
<td>B</td>
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<td>600</td>
<td>–</td>
<td>300</td>
<td>600</td>
<td>300</td>
<td>1500</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>900</td>
<td>300</td>
<td>–</td>
<td>900</td>
<td>600</td>
<td>2100</td>
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<tr>
<td>D</td>
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<td>1800</td>
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<td>2100</td>
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<tr>
<td>F</td>
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<td>6000</td>
<td>1500</td>
<td>2100</td>
<td>3000</td>
<td>2100</td>
<td>–</td>
</tr>
</tbody>
</table>
with/without Skips

The graph compares the distance covered over time for two scenarios: 
- **base** (blue line) 
- **with skip stops** (green line)

The graph highlights:
- Fixed points
- Adjusted points
- Skipped points

Key observations:
- The distance increases with time in both scenarios.
- The graph shows the impact of skipping stops on the overall distance covered.
Optimized Runtimes

Strategy 2

Strategy 3
Comparative Results

curtailed trains
S1-1: 1/12 curtailed
S1-2: 2/12 curtailed
S1-3: 3/12 curtailed

reduced stops
S2-1: 2/12 passing B
S2-2: 4/12 passing B
S2-3: 6/12 passing B

slow down
S3-1: round trip+20[s]
S3-2: round trip+40[s]
S3-3: round trip+60[s]
Discussion

- Trade-off between energy consumption and trip times can be found.
- Curtailed train service (Strategy 1) had much higher increase of trip times than other strategies.
- Reduced train stops (Strategy 2) and slow down (Strategy 3) had very similar characteristics.
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Summary

- Emergent scheduling under restricted energy supply
  - some countermeasures compared
    - energy consumption
    - passenger trip times
  - "reduced number of stops" and "slow down" preferable
- Future scope
  - considering peak power, etc.
Thanks for your kind attention!

http://miyatake.main.jp