Scheduling and Routing Roaming Conductors to Support Single-Person Crew Operations on North American Freight Railways

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Background

► Train crew expenses are a considerable operating cost for private for-profit US freight railways
  • Exceed $6 billion/year for US Class 1 railroads

► US freight train crews typically operate with two-person crews
  • Engineer controls the locomotive
  • Conductor manages the train operation, performs “work events”, and helps to ensure engineer is safely operating the train

► Implementation of Positive Train Control to enforce train speed and movement authority reduces safety benefits of a second crew member in the locomotive cab

► Strong economic incentive for US railroads to adopt one-person train crews for mainline freight trains
  • No regulatory obstacles but “work events” are a practical challenge
Freight Train Work Events

Work events are tasks that require the second crew member (conductor) on the ground outside the train to assist the engineer.

Planned work events
- Delivery or pick-up of railcars at shipper spur tracks and junctions with other railways
- Exchanging blocks of railcars at intermediate terminals
- Adding or removing locomotives at designated locations
- Lining a turnout switch for meets with other trains where there is no centralized traffic control system

Unplanned work events
- Walking train to inspect defects detected by wayside equipment
- Dropping off a defective “bad order” railcar
- Flag protection at some roadway level crossings
- Observe clearances at special locations or during extreme weather

HOW TO HANDLE?
Roaming Conductors

New concept of freight train operations proposed by several major freight railroads

- Single-person crew (engineer) onboard the locomotive
- Assisted by a “roaming conductor” when necessary
  - Not assigned to a particular train
  - Travel via highway vehicles on the roadway network
  - Meet trains to perform scheduled work events
  - May serve multiple trains as required

Potentially economical if the number of roaming conductors is less than the number of onboard conductors for a particular pattern of train paths and work events
Objective: develop an approach to optimally assign train work events to a minimum number of roaming conductors, and determine the feasibility of roaming conductors for different roaming conductor travel scenarios.
Test Problem Setting and Assumptions

- Hypothetical 300-mile (482km) rail corridor
- Average train speed: 55 to 65 mph (88 to 105 km/h)
- Direct access to rail line from parallel highway

- During 12-hour conductor shift
  - Operate 20 trains on the corridor
  - 100 work events randomly distributed between trains and along route
    - Assume work events are completed instantaneously
      (Future work introduces work event duration)

- Variable factor levels
  - Roaming conductor maximum average travel speed
    - 20, 30, 40, 50, 60 mph (32, 48, 64, 80, 97km/h)
  - Number of roaming conductor terminals
    - 1, 2, 3 or 4 distributed evenly along corridor
Mathematical Optimization Model

- Conceptually similar to the Vehicle Routing Problem with Time Windows (VRPTW)
  - Conductor trip = vehicle route
  - Work event = stop
  - Conductors must begin and end shift at their assigned terminal
  - Cannot exceed maximum average travel speed when moving between work events

- Can formulate as a mixed-integer program (MIP)

- Problem size grows quickly
  - Impractical for future tactical application to unplanned work events

\[
\min \sum_{j} X_{0j} \\
\text{Subject to:}
\]

\[
\sum_{j} \sum_{c} X_{0jc} = 1
\]

\[
\sum_{i} \sum_{c} X_{loc} = 1
\]

\[
\sum_{i} \sum_{j} \sum_{c} X_{ijc} \cdot \frac{d_{ij}}{v} \leq 12, \forall c
\]

\[
\sum_{j} \sum_{c} X_{ijc} = 1, \forall i
\]

\[
\sum_{i} \sum_{c} X_{ijc} = 1, \forall j
\]

\[
\sum_{j} X_{tjc} - \sum_{j} X_{jic} = 0, \forall i, \forall c, \forall
\]

\[
x_{ijm} \in \{0,1\}
\]

\[
a_{i} \sum_{j} X_{ijc} \leq w_{ic} \leq b_{i} \sum_{j} X_{ijc}, \forall i
\]

\[
w_{ic} + s_{t} + \frac{d_{ij}}{v} - w_{jc} \leq B_{tj} (1 - X_{tjc}), \forall i \neq j
\]

\[
F \leq w_{oc}, w_{o'c} \leq L, \text{where } F = 0 \text{ hours and } L = 12 \text{ hours, } \forall c
\]
Special Problem Structure

- Roaming conductor problem simplifies some aspects of VRPTW

- One-dimensional travel along the corridor reduces the logical routing options

- Prospective upper bound and initial solution
  - Number of roaming conductors ≤ number of onboard conductors
  - Each conductor follows a single train and handles its work events
  - Initial feasible solution if:
    - Average train speed ≤ maximum average conductor travel speed
    - Initial and final work events for each train allow for adequate conductor travel time from terminal(s)

- Suggests a heuristic approach to create and improve this initial solution may be more efficient than solving the MIP
Example Set of Work Events

► Apply heuristics through Python code

► Construction
  • Initial construction
  • Insert multiple terminals

► Improvement
  • Work event swapping
  • Trip deletion
Initial Construction Algorithm

► Basic concept
  • Dispatch roaming conductor from the terminal
  • Select “closest” work event without violating specified maximum average travel speed
  • Insert work event to path provided path to end terminal satisfies travel speed requirements

► Define “closest” work event?
  • Distance first: nearest work event along corridor
  • Time first: next work event in time
Insert Multiple Terminals

- Initial construction with single terminal leaves some infeasible events at start and end of shift that are far from terminal

- Insert additional terminals and reassign roaming conductors to improve coverage of work events
  - Remaining work events can only be covered by staggered shifts
Improvement Algorithms

► Work event swapping
  • Perturb solution by exchanging work events
  • Accept if average conductor travel speed or total travel distance is decreased
  • Does not reduce number of conductors but helps later steps

► Trip deletion
  • Perturb solution by randomly deleting path
  • Accept deletion if orphaned work events can be feasibly reassigned to other paths

► Monte Carlo approach used to iterate different improvement algorithms and converge to better quality solution
Results After Initial Construction

- Time-first search outperforms distance-first
Addition of Second Terminal

- Second terminal improves work event coverage and feasibility with time-first search
## Solution Improvement

- Roaming conductor maximum average speed 50 mph (80km/h)
- Four roaming conductor terminals
- Reduce from 20 onboard conductors to 16 roaming conductors

<table>
<thead>
<tr>
<th>Number of Roaming Conductors</th>
<th>Average Conductor Travel Speed</th>
<th>Total Distance Traveled</th>
<th>Computation Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Construction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(no iterations or improvements)</td>
<td>19</td>
<td>22.5 mph (36.4km/h)</td>
<td>5,139 miles (8,325km)</td>
</tr>
<tr>
<td>(100 iterations, no improvements)</td>
<td>18</td>
<td>15.5 mph (25.1km/h)</td>
<td>3,339 miles (5,409km)</td>
</tr>
<tr>
<td>After 100 iterations and improvements</td>
<td>16</td>
<td>14.2 mph (23.0km/h)</td>
<td>2,728 miles (4,419km)</td>
</tr>
</tbody>
</table>
Summary and Future Work

► Developed algorithm to assign work events to roaming conductors
► Demonstrated that number of roaming conductors can be lower than the number of onboard conductors for hypothetical corridor
► Suggests the operating concept is a potential pathway to single-person crews on US mainline freight trains

► Future work will eliminate simplifying assumptions
  • Introduce work event duration
  • Consider work event dependency
    - Late execution of one work event delays subsequent work events for that train
  • Overlapping shifts
  • Tactical model with unplanned work events
  • Actual corridor settings with more complex topography and access
Thank you for your attention!

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