System-wide Delay Optimizer for Train Schedules at Intermodal Facilities

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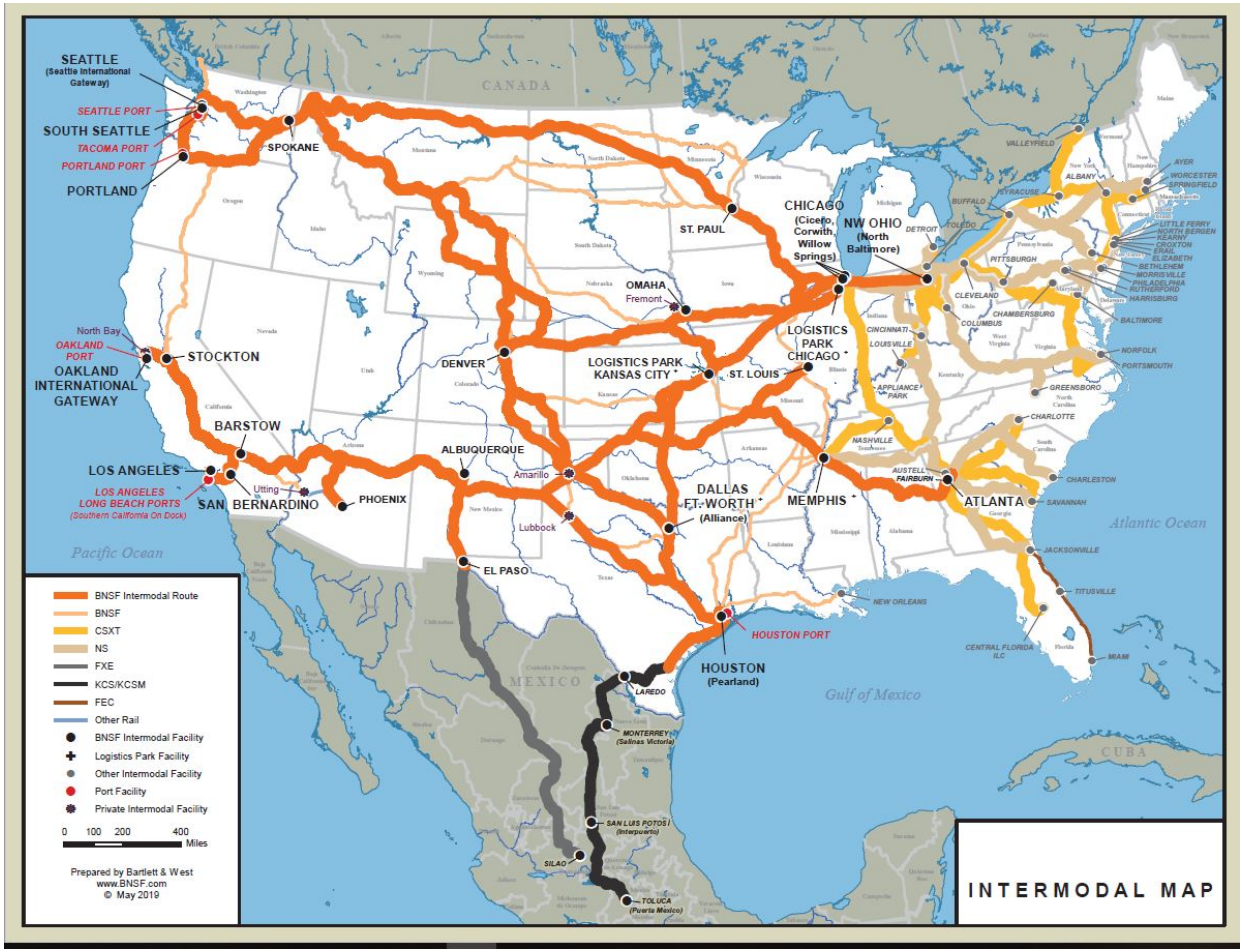
Intermodal Network



- Largest freight railroad network in North America
- 28 U.S. states and 3 Canadian provinces
- 25 intermodal facilities
- 10.7 million carloads shipped in 2019

Source:
https://www.bnsf.com/ship-with-bnsf/maps-and-shipping-locations/pdf/small-intermodal-map.JPG
https://www.bnsf.com/about-bnsf/financial-information/pdf/performance-update-2q-2019.pdf

Problem Description

- A network has a set of hubs and trains
  - Each hub has a strip track (with max footage) and at most 2 lead tracks per direction. A hub can have either North/South leads or East/West leads.
  - Each train departs at an origin hub, possibly stops at one or multiple transit hubs before arriving at the destination hub
  - The time the train occupy strip/lead tracks depends on its priority, length and activity (e.g. transiting)
- Goal: Minimizing the cost associated with delaying/advancing trains to meet capacity constraints
- Assumption: All strip tracks are considered as 1 single big strip track that has the hub's total footage

Variables

Variables

- x_{it}: binary variable indicating if event i (i.e. departure or arrival) happens at time t
- y_{it}: binary variable indicating if event i is occupying the strip track at at time t
- z_{it}^{k}: binary variable indicating if event i is occupying lead track k at time t

Data

- c_{it}: cost associated with event i occuring at time t
- s_i: length (ft) of train associated with event i
- r_i: transportation time (hours) associated with event i (i.e., 0 hour for departures)
- d_i: number of hours taken to process event i on strip track
- l_i: number of hours taken to process event i on lead track
- h_i: the hub where event i takes place
- p^i: the index of the event preceding event i
- L_h^k: capacity of lead track k at hub h
- U_h^k: capacity of strip track k at hub h
- T_i: set of time periods where event i is allowed to occur
- T_i^{max}: latest time period where event i is allowed to occur
- P: set of all trains with that have at least 1 preceding train.
- Λ: set of all events where Λ^{TD} and Λ^{TA} are the set of all departing and arriving events respectively (Note: $\Lambda = \Lambda^{TD} \cup \Lambda^{TA}$)

Formulation

$$\text{minimize} \quad \sum_{i \in \Lambda^{TA}} \sum_{t \in T_i} c_{it} x_{it} \tag{1}$$

$$\text{s.t.} \quad \sum_{t \in T_i} x_{it} = 1 \qquad \forall i \in \Lambda \tag{2}$$

$$x_{p^i t} \leq \sum_{t'=t+r_i}^{T_i^{max}} x_{it'} \qquad \forall i \in P, \forall t \in T_{p^i} \tag{3}$$

Formulation (2)

s.t.

$$\sum_{k=0}^{d_i-1} y_{i(t+l_i+k)} \geq d_i x_{it} \qquad \forall i \in \Lambda^{TA}, \forall t \in T_i \qquad (4)$$

$$\sum_{k=0}^{d_i-1} y_{i(t-l_i-d_i+k)} \geq d_i x_{it} \qquad \forall i \in \Lambda^{TD}, \forall t \in T_i \qquad (5)$$

$$\sum_{k=0}^{l_i-1} z^0_{i(t+k)} \geq l_i(1-\gamma_i) x_{it} \qquad \forall i \in \Lambda^{TA}, t \in T_i \qquad (6)$$

$$\sum_{k=0}^{l_i-1} z^0_{i(t-d_i+k)} \geq l_i(1-\gamma_i) x_{it} \qquad \forall i \in \Lambda^{TD}, t \in T_i \qquad (7)$$

$$\sum_{k=0}^{l_i-1} z^1_{i(t+k)} \geq l_i \gamma_i x_{it} \qquad \forall i \in \Lambda^{TA}, t \in T_i \qquad (8)$$

Formulation (3)

s.t.

$$\sum_{k=0}^{l_i-1} z^1_{i(t-d_i+k)} \geq l_i \gamma_i x_{it} \qquad \forall i \in \Lambda^{TD}, t \in T_i \qquad (9)$$

$$\sum_{i \in \Lambda: h_i = h} s_i y_{it} \leq U_h \qquad \forall t \in T, \forall h \in H \qquad (10)$$

$$\sum_{i \in \Lambda: h_i = h} z^k_{it} \leq L^k_h \qquad \forall t \in T, \forall h \in H, \forall k = 0, 1 \qquad (11)$$

$$x_{it} \in \{0, 1\} \qquad \forall i \in \Lambda, \forall t \in T_i \qquad (12)$$

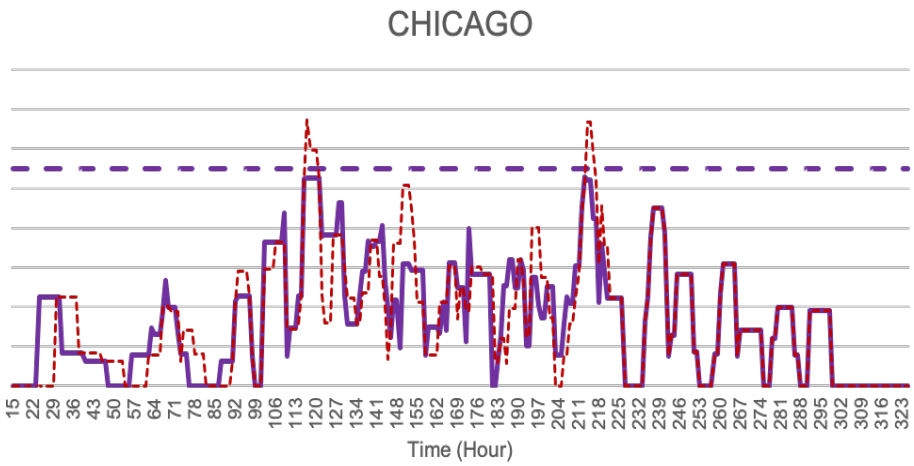
$$y_{it} \in \{0, 1\} \qquad \forall i \in \Lambda, \forall t \in T \qquad (13)$$

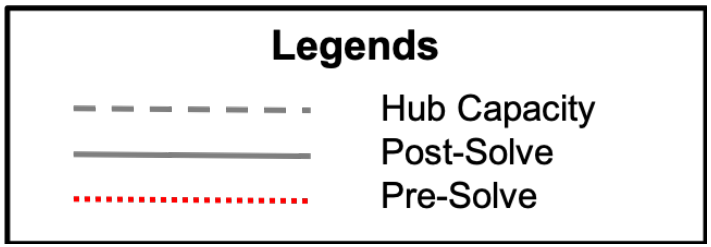
$$z^k_{it} \in \{0, 1\} \qquad \forall i \in \Lambda, \forall t \in T, \forall k = 0, 1 \qquad (14)$$

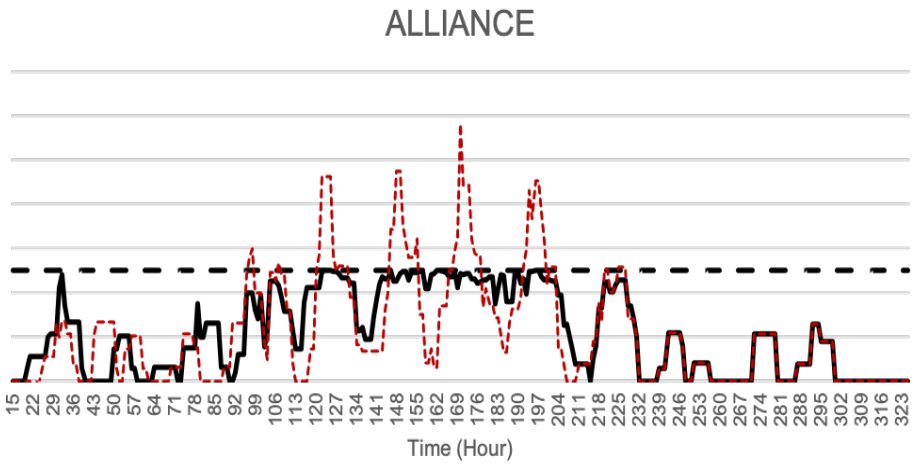
Results

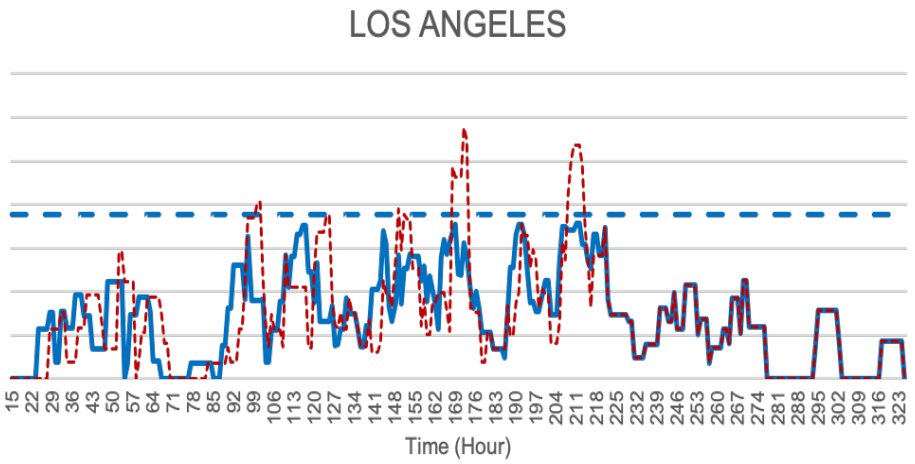
- 8-day period, 411 trains (i.e. at least 822 events), 39 hubs, 3 levels of priority
  - Z-trains (Highest priority): +/- 4 hours, cost of 4 units per 1-hour deviation
  - Q-trains (High priority): +/- 6 hours, cost of 2 units per 1-hour deviation
  - S-trains (Not-as-High priority): +/- 12 hours, cost of 1 units per 1-hour deviation

Results - Capacity

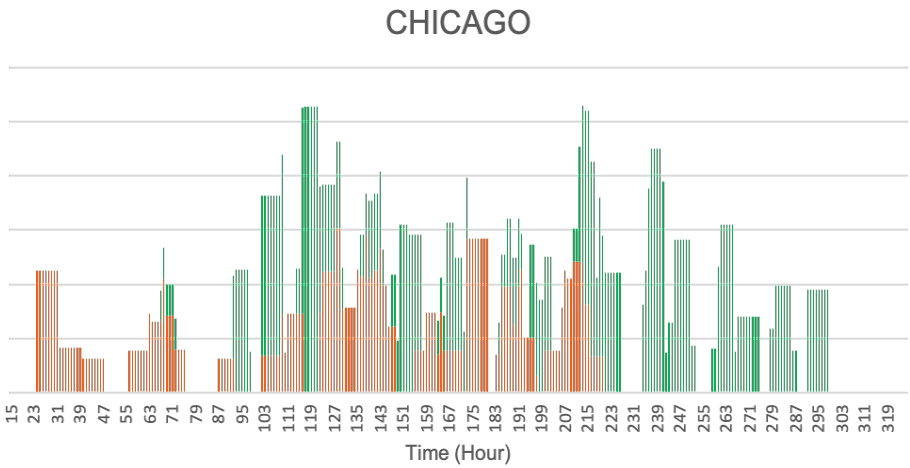


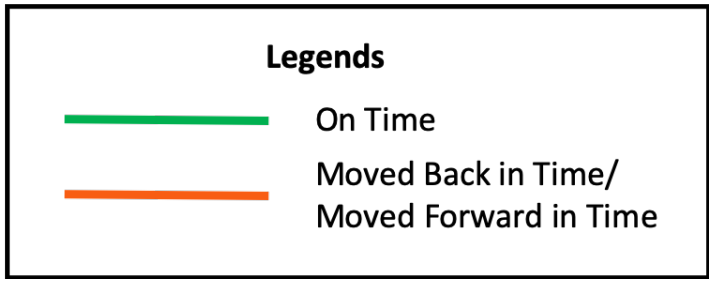


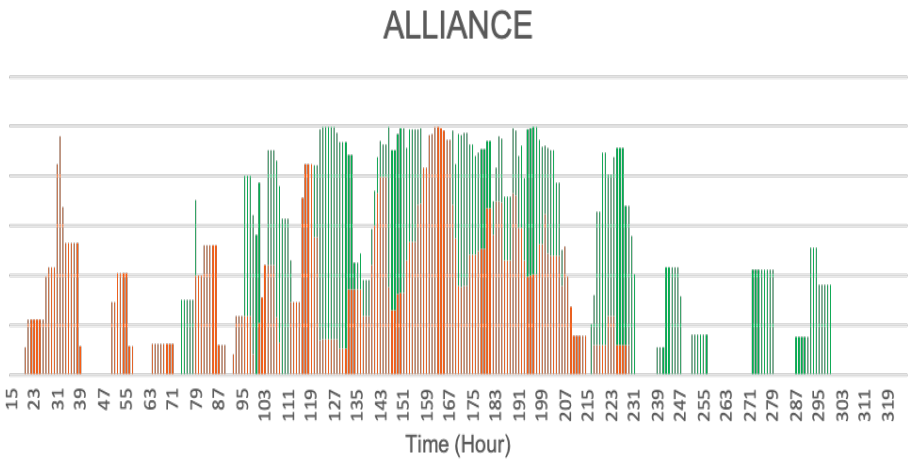


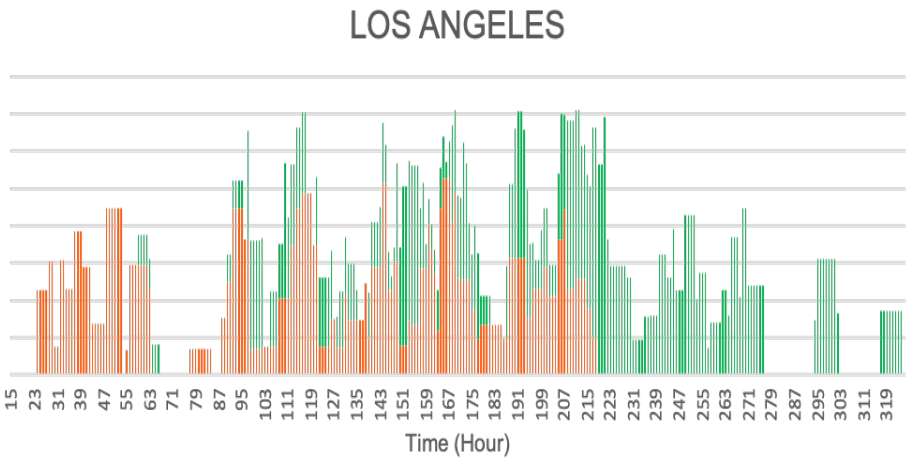


Results - Delays & Advances









Observations and Extension

- Observations:
  - Optimal solution found in less than 1 minute
  - CPLEX performs better when x-, y- and z-variables are binary instead of continuous
- Extension:
  - Multi-origin and multi-destination model can be achieved by keeping a list of predecessors (instead of a single predecessor)