

informs ANNUAL MEETING | 2020 VIRTUAL



**An optimization method for
train rescheduling and travel
time estimation problem**

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OUTLINE

- **Problem Description**
- **Model Formulation**
- **Solution Approach**
- **Experiment Result**



1. Problem Description

➤ Station type

- *Origin*
- *Int*
- *Stop*
- *Dest*

A station plays different roles for different trains.

➤ Limitation for stations

- At *Int* station, if arrive earlier than PAT, go ahead and leave earlier than PDT
- Do **NOT** leave earlier than PDT at *Origin* and *Stop* station

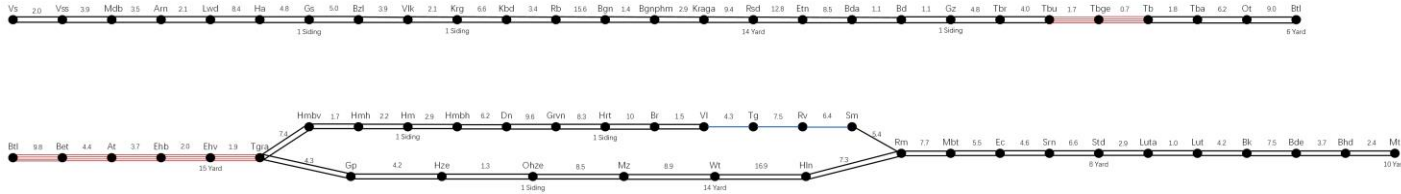
PAT: planned arrival time

PDT: planned departure time



1. Problem Description

➤ Railway Network



Station with only main tracks tracks

Station with siding tracks: Gs, Krg, Gz, Hm, Hrt, Ohze

Station with yard tracks: Rsd, Btl, Ehv, Wt, Std, Mt

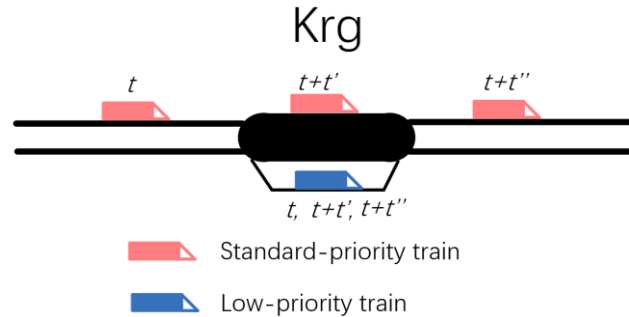
Station with industrial spur: only one for each station without yard



1. Problem Description

➤ Train priority and overtake

- *Low*
- *Standard*



Standard-priority trains can overtake Low-priority trains at stations



1. Problem Description

➤ Using of main track, siding, industrial spur and yard

Main track: stop at or pass station

Siding: stop at or pass station

Yard: pick-up/set-off railcars, or be used as temporarily siding tracks

Industrial spur: pick-up/set-off railcars

5 minutes time penalty for red situations.



1. Problem Description

➤ Availability of locomotive, crew and yard

Work	Dwell time
Pick-up/set-off railcars	yard
Crew change	crew
Depart from <i>Origin</i> station	yard&loco

Dwell time	Value
yard	$X \sim \text{LogN}(0.5, 0.25)$
crew	$X \sim \text{LogN}(0.1, 1)$
loco	$X \sim \text{LogN}(0.25, 0.1)$



1. Problem Description

➤ Availability of locomotive, crew and yard

Dwell time	Value
crew	$X \sim \text{LogN}(0.1, 1)$

$$y_{r,n}^{\text{exit}} \geq y_{r,n}^{\text{entr}} + t_{r,n}^{\text{crew}} \Rightarrow P\{y_{r,n}^{\text{exit}} - y_{r,n}^{\text{entr}} \geq t_{r,n}^{\text{crew}}\} \geq \eta_{r,n}^{\text{crew}}$$

$$\text{Set } v = y_{r,n}^{\text{exit}} - y_{r,n}^{\text{entr}} \Rightarrow P\{t_{r,n}^{\text{entr}} \leq v\} \geq \eta_{r,n}^{\text{crew}}$$

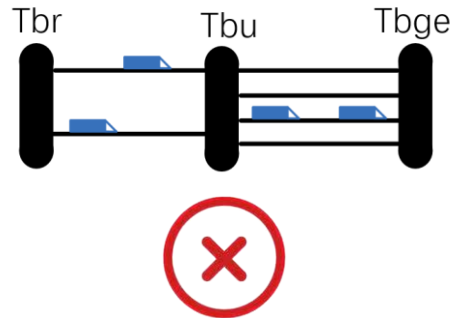
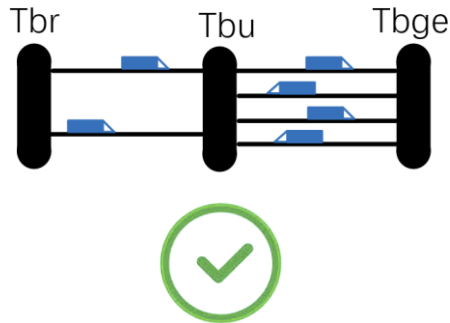
$$\text{Standardization: } \Phi\left(\frac{v - \mu}{\delta}\right) \geq \eta_{r,n}^{\text{crew}}$$

$$\text{Relaxation to deterministic linear constraints: } v - \mu - \delta\Phi^{-1}(\eta_{r,n}^{\text{crew}}) \geq 0$$



1. Problem Description

- **Parameters and rules of train operating in sections**
 - Speed: $\min(\text{train maximum speed}, \text{allowed speed of tracks})$
 - Section occupation: one train on one track of one section at any time



OUTLINE

- Problem Description
- **Model Formulation**
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- Experiment Result



2. Model Formulation

➤ Assumption

- The length of siding tracks, yard tracks and industrial spurs are sufficient for any of the given train.
- Maximum train length and tonnage can be ignored.
- Switch orientation is appropriately matched to the movement action of current train.
- Acceleration and deceleration when entering and leaving stations can be ignored.
- Each station has crossovers, which can guarantee that trains can run to any parallel tracks connected to the station.
- Sidings and industrial spurs are accessible from any of the main tracks via the crossovers.
- There is no penalty time to utilize a crossover.



2. Model Formulation

➤ Objective function

$$\min \sum_{r \in R} \left(\sum_{n \in N_r \cup n_r^o} (D_{r,n}^{dep,+} + D_{r,n}^{dep,-}) \right) + \sum_{n \in N_r \cup n_r^d} (D_{r,n}^{ari,+} + D_{r,n}^{ari,-})$$



the sum of deviation
time of departure time
at each station except
Dest stations



the sum of deviation
time of arrival time at
each station except
Origin stations



2. Model Formulation

➤ **Deviate time to the scheduled time at the stations**

$$y_{r,n}^{exit} = t_{r,n}^{dep} + D_{r,n}^{dep,+} - D_{r,n}^{dep,-} \quad \forall r \in R, n \in N_r \cup n_r^o.$$

$$y_{r,n}^{entr} = t_{r,n}^{ari} + D_{r,n}^{ari,+} - D_{r,n}^{ari,-} \quad \forall r \in R, n \in N_r \cup n_r^d.$$

The deviation time at each station can be calculated by the actual time and scheduled time.

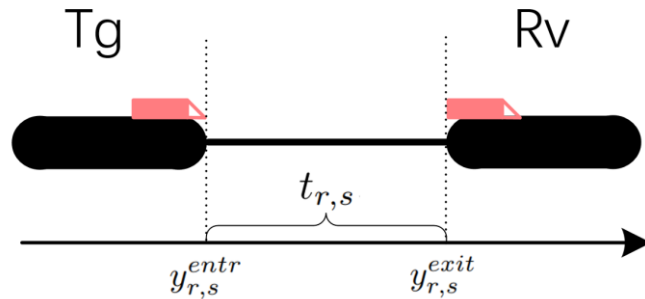


2. Model Formulation

➤ Section usage and running time constraints

$$y_{r,s}^{entr} \leq Mx_{r,s}, \quad \forall r \in R, s \in S_r.$$

$$y_{r,s}^{exit} = y_{r,s}^{entr} + x_{r,s}t_{r,s}, \quad \forall r \in R, s \in S_r.$$



2. Model Formulation

- **Tracks selection and operation time constraints**
- Tracks selection in stations

$$\sum_{w \in W_{r,n}} z_{r,n,w} = 1, \quad \forall r \in R, n \in N_r.$$

$$z_{r,n,w} = 1, \quad \forall r \in R, n \in N_r^{order} \cap (N^{it} \cup N^{si}), w = w^{in}.$$

$$z_{r,n,w} = 1, \quad \forall r \in R, n \in N_r^{order} \cap N^{de}, w = w^{ya}.$$

If the train needs to pick-up/set-off railcars, it has to select yard tracks or industrial spur



2. Model Formulation

➤ Tracks selection and operation time constraints

- Operation time constraints – basic constraint and 5 minutes penalty

$$y_{r,n}^{exit} \geq t_{r,n}^{dep}, \quad \forall r \in R, n \in N_r^{stop}.$$

$$y_{r,n}^{exit} \geq y_{r,n}^{entr} + \sum_{w \in W_{r,n}} t_{r,n,w}^{dewll} z_{r,n,w}, \quad \forall r \in R, n \in N_r \setminus (N_r^{order} \cup N_r^{crew})$$

A train can not leave earlier than PDT at *Stop* stations.

A train must have a 5 minutes penalty time if it uses siding tracks and industrial spur.



2. Model Formulation

- **Tracks selection and operation time constraints**
- Operation time constraints – crew change constraints

$$y_{r,n}^{exit} \geq y_{r,n}^{entr} + \sum_{w \in W_{r,n}} t_{r,n,w}^{dewll} z_{r,n,w} + t_{r,n}^{crew}, \quad \forall r \in R, n \in N_r^{crew} \setminus N_r^{order}.$$

$$y_{r,n}^{exit} \geq y_{r,n}^{entr} + \sum_{w \in W_{r,n}} t_{r,n,w}^{dewll} z_{r,n,w} + t_{r,n}^{crew}, \quad \forall r \in R, n \in N_r^{crew} \cap N_r^{order}.$$

$$P\left\{t_{r,n}^{crew} \geq \tau_{r,n}^{crew}\right\} \geq \eta_{r,n}^{crew}, \quad \forall r \in R, n \in N_r^{crew}.$$

A train can implement crew change and work order simultaneously in the yard, which means $t_{r,n,w^{ya}}^{dewll} = 5$.



2. Model Formulation

- **Tracks selection and operation time constraints**
- Operation time constraints – work order constraints

$$y_{r,n}^{exit} \geq y_{r,n}^{entr} + \sum_{w \in W_{r,n}} t_{r,n,w}^{dwell} z_{r,n,w} + t_{r,n}^{order}, \quad \forall r \in R, n \in N_r^{order}.$$

$$P\left\{t_{r,n}^{order} \geq \tau_{r,n}^{order}\right\} \geq \eta_{r,n}^{order}, \quad \forall r \in R, n \in N_r^{order}.$$

The dwell time of yard must be consider if a train needs to pick-up/set-off railcars



2. Model Formulation

- **Tracks selection and operation time constraints**
- Operation time constraints – locomotive constraints

$$P\left\{y_{r,n}^{exit} \geq y_{r,n}^{entr} + t_{r,n}^{loco}\right\} \geq \eta_{r,n}^{loco}, \quad \forall r \in R, n = n_r^o.$$

The dwell time of locomotive need to be considered only at the *Origin* station of a train.



2. Model Formulation

➤ Train routing constraints

$$\sum_{s \in S_{r,n}^{out}} x_{r,s} - \sum_{s \in S_{r,n}^{in}} x_{r,s} = \begin{cases} 1 & n = n_r^o \\ -1 & n = n_r^d \\ 0 & n \in N_r \end{cases}, \quad \forall r \in R.$$

A train will only choose one route connecting its origin and destination stations, resulting in a chain of sections.



2. Model Formulation

➤ Conflicts of two trains on the sections

$$M(1 - x_{r',s}) + M(1 - x_{r,s}) + y_{r',s}^{entr} - y_{r,s}^{exit} \geq -M(1 - \mu_{r,r',s}), \quad \forall r, r' \in R, s \in S_r, s \in S_{r'}$$

$$M(1 - x_{r',s}) + M(1 - x_{r,s}) + y_{r,s}^{entr} - y_{r',s}^{exit} \geq -M\mu_{r,r',s}, \quad \forall r, r' \in R, s \in S_r, s \in S_{r'}$$

$$\mu_{r,r',s} = \begin{cases} 1 & \text{train } r \text{ precedes train } r' \\ 0 & \text{train } r' \text{ precedes train } r \end{cases}$$



2. Model Formulation

➤ Capacity constraints of the stations with a yard

- Constraints of two trains using the same yard track – entrance time constraints $z_{r,n,w}, z_{r',n,w} = 1$

$$y_{r',n}^{entr} - y_{r,n}^{entr} \leq M(1 - \gamma_{r,r',n,w}) + M(1 - z_{r,n,w}) + M(1 - z_{r',n,w}), \quad \forall r, r' \in R, n \in N_r \cap N_{r'} \cap N^{de}$$

$$y_{r,n}^{entr} - y_{r',n}^{entr} \leq M\gamma_{r,r',n,w} + M(1 - z_{r,n,w}) + M(1 - z_{r',n,w}), \quad \forall r, r' \in R, n \in N_r \cap N_{r'} \cap N^{de}$$

For resource w of station n :

$$\gamma_{r,r',n,w} = \begin{cases} 1 & \text{train } r' \text{ arrives earlier than } r \\ 0 & \text{train } r \text{ arrives earlier than } r' \end{cases}$$



2. Model Formulation

- **Capacity constraints of the stations with a yard**
- Constraints of two trains using the same yard track – exit time constraints

$$z_{r,n,w}, z_{r',n,w} = 1$$

$$y_{r',n}^{exit} - y_{r,n}^{entr} \leq M(1 - \delta_{r,r',n,w}) + M(1 - z_{r,n,w}) + M(1 - z_{r',n,w}), \quad \forall r, r' \in R, n \in N_r \cap N_{r'} \cap N^{de}$$

$$y_{r,n}^{entr} - y_{r',n}^{exit} \leq M\delta_{r,r',n,w} + M(1 - z_{r,n,w}) + M(1 - z_{r',n,w}), \quad \forall r, r' \in R, n \in N_r \cap N_{r'} \cap N^{de}$$

For resource w of station n :

$$\delta_{r,r',n,w} = \begin{cases} 1 & \text{train } r' \text{ departs earlier than } r \text{ arrives} \\ 0 & \text{train } r \text{ arrives earlier than } r' \text{ departs} \end{cases}$$



2. Model Formulation

- **Capacity constraints of the stations with a yard**
- Constraints of capacity

$$\sum_{r' \in R} \gamma_{r,r',n,w} - \sum_{r' \in R} \delta_{r,r',n,w} + z_{r,n,w} \leq c_n, \forall r \in R, n \in N_r \cap N_{r'} \cap N^{de}, w \in W_n.$$

$$\delta_{r,r',n,w} \leq z_{r,n,w}, \forall r \in R, n \in N_r \cap N^{de}, w \in W_n.$$

$$\delta_{r,r',n,w} \leq z_{r',n,w}, \forall r \in R, n \in N_{r'} \cap N^{de}, w \in W_n.$$



2. Model Formulation

➤ Capacity constraints of the stations without yard

• Constraints of time

$$y_{r',n}^{entr} - y_{r,n}^{entr} \leq M(1 - \kappa_{r,r',n}) + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r,n,w}) + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r',n,w}) \quad \forall r, r' \in R, n \in (N_r \cap N_{r'}) \cap (N^{si} \cup N^{it})$$

$$y_{r,n}^{entr} - y_{r',n}^{entr} \leq M\kappa_{r,r',n} + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r,n,w}) + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r',n,w}) \quad \forall r, r' \in R, n \in (N_r \cap N_{r'}) \cap (N^{si} \cup N^{it})$$

$$y_{r',n}^{exit} - y_{r,n}^{entr} \leq M(1 - \lambda_{r,r',n}) + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r,n,w}) + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r',n,w}) \quad \forall r, r' \in R, n \in N_r \cap N_{r'} \cap (N^{si} \cup N^{it})$$

$$y_{r,n}^{entr} - y_{r',n}^{exit} \leq M\lambda_{r,r',n} + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r,n,w}) + M(1 - \sum_{w \in W_n \setminus w^{in}} z_{r',n,w}) \quad \forall r, r' \in R, n \in N_r \cap N_{r'} \cap (N^{si} \cup N^{it})$$

$$\kappa_{r,r',n} = \begin{cases} 1 & \text{train } r' \text{ arrives earlier than } r \\ 0 & \text{train } r \text{ arrives earlier than } r' \end{cases}$$

$$\lambda_{r,r',n} = \begin{cases} 1 & \text{train } r' \text{ departs earlier than } r \text{ arrives} \\ 0 & \text{train } r \text{ arrives earlier than } r' \text{ departs} \end{cases}$$



2. Model Formulation

- **Capacity constraints of the stations without yard**
- Constraints of capacity

$$\sum_{r' \in R} \kappa_{r,r',n} - \sum_{r' \in R} \lambda_{r,r',n} + \sum_{w \in W_n \setminus w^{in}} z_{r,n,w} \leq c_n, \forall r \in R, n \in N_r \cap N_{r'} \cap (N^{si} \cup N^{it}).$$

$$\lambda_{r,r',n} \leq \sum_{w \in W_n \setminus w^{in}} z_{r,n,w}, \forall r \in R, n \in N_r \cap (N^{si} \cup N^{it}).$$

$$\lambda_{r,r',n} \leq \sum_{w \in W_n \setminus w^{in}} z_{r',n,w}, \forall r \in R, n \in N_{r'} \cap (N^{si} \cup N^{it}).$$



2. Model Formulation

- **Capacity constraints of the stations without yard**
- Constraints of industrial spur capacity

$$y_{r',n}^{exit} - y_{r,n}^{entr} \leq M(1 - \delta_{r,r',n,w}) + M(1 - z_{r,n,w}) + M(1 - z_{r',n,w}), \quad \forall r, r' \in R, n \in N_r \cap N_{r'}, w = w^{in}$$

$$y_{r,n}^{exit} - y_{r',n}^{entr} \leq M\delta_{r,r',n,w} + M(1 - z_{r,n,w}) + M(1 - z_{r',n,w}), \quad \forall r, r' \in R, n \in N_r \cap N_{r'}, w = w^{in}$$

$$\delta_{r,r',n,w} = \begin{cases} 1 & \text{train } r' \text{ departs earlier than } r \text{ arrives} \\ 0 & \text{train } r \text{ arrives earlier than } r' \text{ departs} \end{cases}$$



2. Model Formulation

➤ Constraints of overtaking at the stations

- Constraints of overtaking

train r overtakes r' at station n : $\alpha_{r,r',n}, \beta_{r,r',n} = 1$

$$y_{r',n}^{entr} - y_{r,n}^{entr} \leq M(1 - \alpha_{r,r',n}), \forall dir_r = dir_{r'}, \quad \forall r, r' \in R, n \in N_r \cap N_{r'}$$

$$y_{r,n}^{entr} - y_{r',n}^{entr} \leq M\alpha_{r,r',n}, \forall dir_r = dir_{r'}, \quad \forall r, r' \in R, n \in N_r \cap N_{r'}$$

$$y_{r,n}^{exit} - y_{r',n}^{exit} \leq M(1 - \beta_{r,r',n}), \forall dir_r = dir_{r'}, \quad \forall r, r' \in R, n \in N_r \cap N_{r'}$$

$$y_{r',n}^{exit} - y_{r,n}^{exit} \leq M\beta_{r,r',n}, \forall dir_r = dir_{r'}, \quad \forall r, r' \in R, n \in N_r \cap N_{r'}$$

No overtaking

$$\alpha_{r,r',n} + \beta_{r,r',n} \leq 1, \forall dir_r = dir_{r'}, pri_r \leq pri_{r'}, n \in N^r \cap N^{r'} \cap N^{si} \cap N^{de}$$

$$\alpha_{r,r',n} + \beta_{r,r',n} \leq 1, \forall dir_r = dir_{r'}, \forall r, r' \in R, c_n = 1, n \in N^r \cap N^{r'} \cap N^{it}.$$



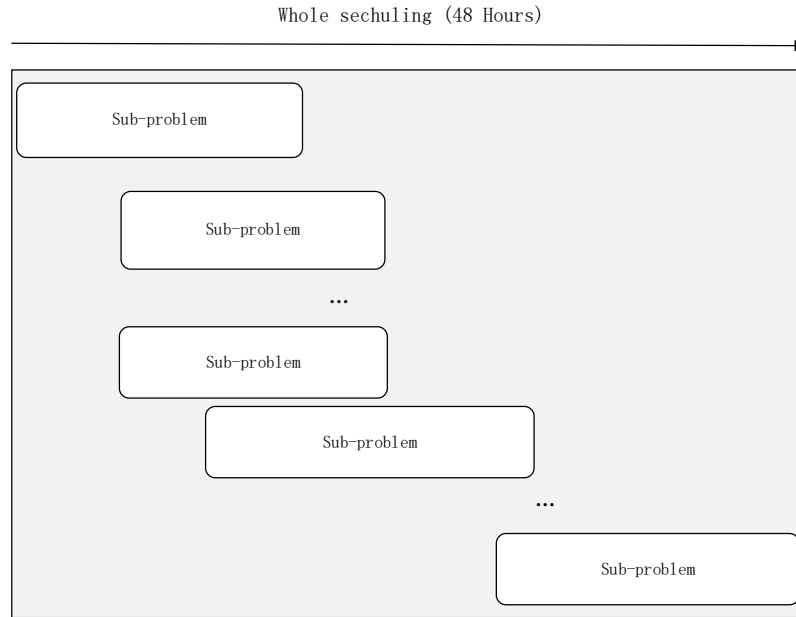
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3. Solution Approach

➤ Rolling horizon optimization

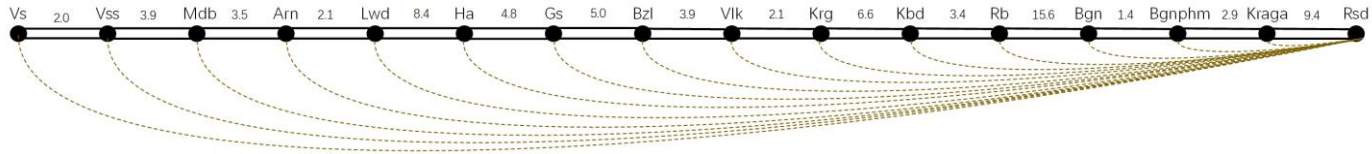


3. Solution Approach

➤ Dummy sections

Some trains could not arrive at the destination station in the horizon, which will lead infeasibility of the model.

Add dummy sections from *Origin* station to *Dest* station for a train



3. Solution Approach

➤ Update model

- New decision variable

$\theta_{r,n}^{dum}$, 0-1 variable, equals to 1 when train r selects the dummy section to run to the destination station directly from station n

- New set and new parameter

H , set of all horizons, index by h , $h \in H$

$t^{h,b}, t^{h,e}$, the begin time and end time of horizon h



3. Solution Approach

➤ Update model

- Extra constraints of section usage and running time

$$y_{r,s}^{exit} \leq t^{h,e}, \quad \forall r \in R, s \in S_r, h \in H$$

- Update of operation selection and operation time constraints

$$\sum_{w \in W_{r,n}} z_{r,n,w} \leq \sum_{s \in S_{r,n}^{out}} x_{r,s}, \quad \forall r \in R, n \in N_r.$$

$$z_{r,n,w} = \sum_{s \in S_{r,n}^{out}} x_{r,s}, \quad \forall r \in R, n \in N_r^{order} \cap (N^{it} \cup N^{si}), w = w^{in}.$$

$$z_{r,n,w} = \sum_{s \in S_{r,n}^{out}} x_{r,s}, \quad \forall r \in R, n \in N_r^{order} \cap N^{de}, w = w^{ya}.$$

$$y_{r,n}^{exit} \geq y_{r,n}^{entr} + \sum_{w \in W_{r,n}} t_{r,n,w}^{dewll} z_{r,n,w} + \sum_{w \in W_{r,n}} t_{r,n}^{crew} z_{r,n,w}, \quad \forall r \in R, n \in N_r^{crew} \setminus N_r^{order}.$$

$$y_{r,n}^{exit} \geq y_{r,n}^{entr} + \sum_{w \in W_{r,n}} t_{r,n,w}^{dewll} z_{r,n,w} + \sum_{w \in W_{r,n}} t_{r,n}^{crew} z_{r,n,w}, \quad \forall r \in R, n \in N_r^{crew} \cap N_r^{order}.$$

$$y_{r,n}^{exit} \geq y_{r,n}^{entr} + \sum_{w \in W_{r,n}} t_{r,n,w}^{dewll} z_{r,n,w} + \sum_{w \in W_{r,n}} t_{r,n}^{order} z_{r,n,w}, \quad \forall r \in R, n \in N_r^{order}.$$

$$P\left\{y_{r,n}^{exit} \geq y_{r,n}^{entr} + t_{r,n}^{loco}(1 - \theta_{r,n}^{dum})\right\} \geq \eta_{r,n}^{loco}, \quad \forall r \in R, n = n_r^o.$$



3. Solution Approach

➤ Update model

- Update of the exit time and entrance time transition at the stations

$$y_{r,n}^{entr} = \sum_{s \in S_{r,n}^{in}} y_{r,s}^{exit} + \sum_{s \in S^{dum}} y_{r,s}^{exit} \theta_{r,n}^{dum}, \quad \forall r \in R, n \in N_r \cup n_r^d.$$

$$y_{r,n}^{exit} = \sum_{s \in S_{r,n}^{out}} y_{r,s}^{entr} + y_{r,s'}^{entr} \theta_{r,n}^{dum}, \quad \forall r \in R, n \in N_r \cup n_r^o, s' = S_{r,n}^{dum}$$

- Update of the train routing constraints

$$\sum_{s \in S_{r,n}^{out}} x_{r,s} - \sum_{s \in S_{r,n}^{in}} x_{r,s} + \theta_{r,n}^{dum} = 1, \quad n = n_r^o, \forall r \in R.$$

$$\sum_{s \in S_{r,n}^{out}} x_{r,s} - \sum_{s \in S_{r,n}^{in}} x_{r,s} + \sum_{n' \in N_r \cup n_r^o} \theta_{r,n'}^{dum} = -1, \quad n = n_r^d, \forall r \in R$$

$$\sum_{s \in S_{r,n}^{out}} x_{r,s} - \sum_{s \in S_{r,n}^{in}} x_{r,s} + \theta_{r,n}^{dum} = 0, \quad n = N_r, \forall r \in R.$$

- Update of the calculation of station capacity

$$\sum_{h' \in H} c_n^{h'} + \sum_{r' \in R} \gamma_{r,r',n,w} - \sum_{r' \in R} \delta_{r,r',n,w} + z_{r,n,w} \leq c_n, \forall r \in R, n \in N_r \cap N_{r'} \cap N^{de}, w \in W_n.$$

$$\sum_{h' \in H} c_n^{h'} + \sum_{r' \in R} \kappa_{r,r',n} - \sum_{r' \in R} \lambda_{r,r',n} + \sum_{w \in W_n \setminus w^{in}} z_{r,n,w} \leq c_n, \forall r \in R, n \in N_r \cap N_{r'} \cap (N^{si} \cup N^{it})$$



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- **Experiment Result**



4. Experiment Result

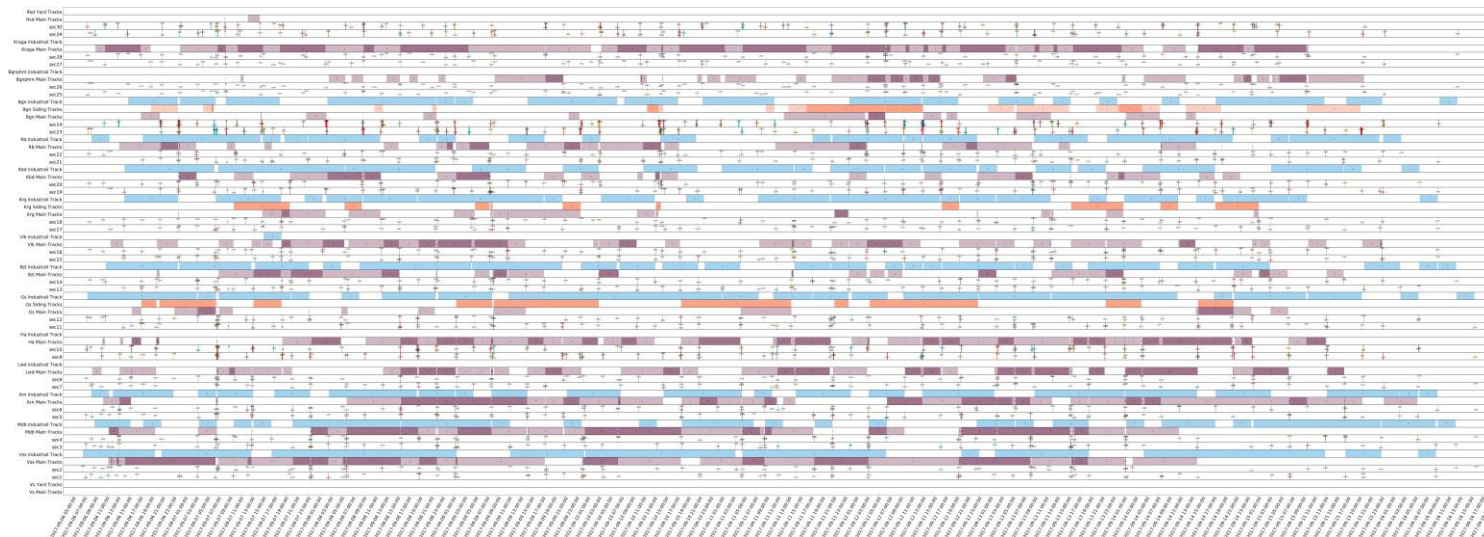
- **Case 1:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order}$ = 90%
- Value of dwell time (minutes)

Dwell time	Value (minutes)
$t_{r,n}^{order}$	188
$t_{r,n}^{crew}$	239
$t_{r,n}^{loco}$	115



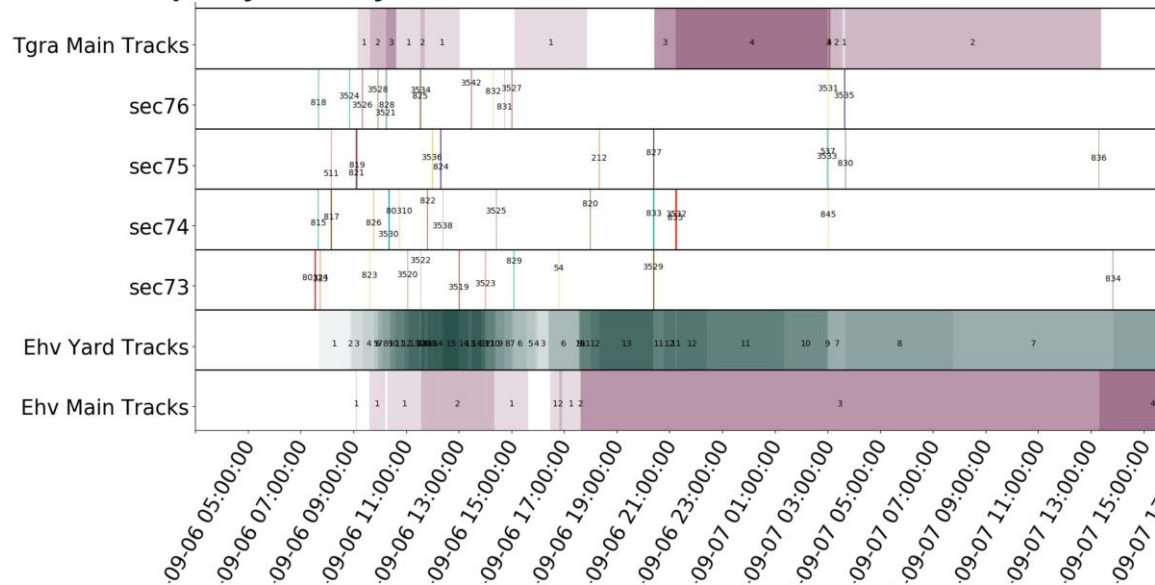
4. Experiment Result

- **Case 1:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order}$ = 90%
- Result displayed by Gantt charts



4. Experiment Result

- **Case 1:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order}$ = 90%
- Result displayed by Gantt charts

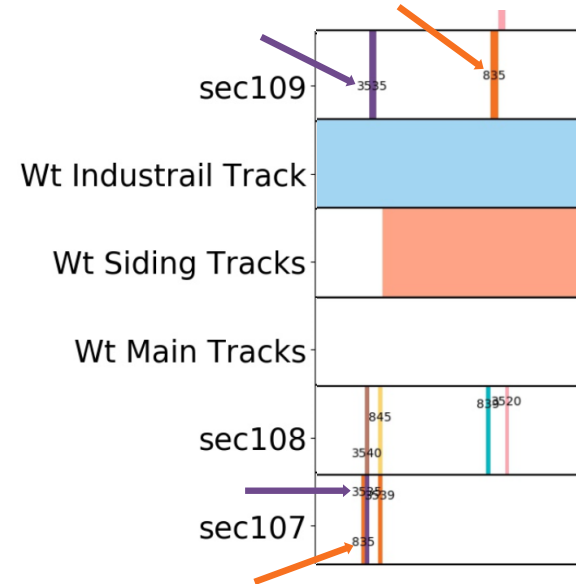


4. Experiment Result

- **Case 1:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order}$ = 90%
- Result displayed by Gantt charts – Overtake example

trainNo	Color	Station	AAT	ADT
835	Orange	Wt	9/8/2017 03:50:00	9/8/2017 07:03:00
3535	Purple	Wt	9/8/2017 03:56:00	9/8/2017 03:56:00

AAT: actual arrival time ADT: actual departure time



4. Experiment Result

➤ **Case 1:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order} = 90\%$

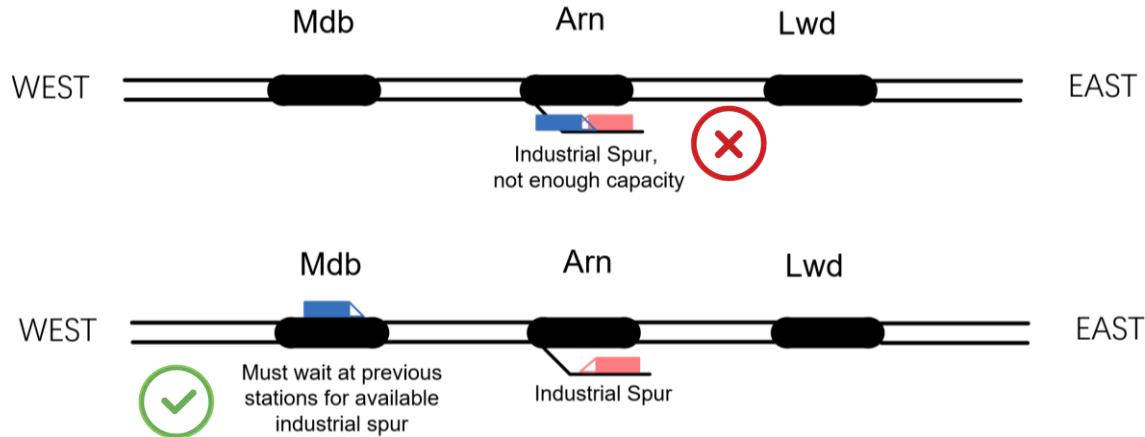
- Solution results

Item	Value(minutes)
objective function	104493551
average delay time of each train at its destination station	7514
maximum delay time of each train at its destination station	17916
average delay time of all trains at all stations	6917
maximum delay time of all trains at all stations	17916
Last actual arrival time	9/20/2017 9:43 AM



4. Experiment Result

- **Case 1:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order} = 90\%$
- Why so long? A kind of single-track railway scheduling problem, hardly to solve



4. Experiment Result

- **Case 1:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order} = 90\%$
- Why so long? A kind of single-track railway scheduling problem, hardly to solve

trainNo	Direction	Station	PAT	PDT	AAT	ADT
2247	E	Bgn(Spur)	9/6/2017 11:42:00	9/6/2017 11:44:00	9/8/2017 04:13:00	9/8/2017 07:26:00
2232	W	Bgn(Spur)	9/6/2017 13:14:00	9/6/2017 13:16:00	9/8/2017 07:26:00	9/8/2017 10:39:00

- Values of dwell time are large



4. Experiment Result

- **Case 2:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order} = 50\%$
- Value of dwell time (minutes)

Dwell time	Value (minutes)
$t_{r,n}^{order}$	112
$t_{r,n}^{crew}$	109
$t_{r,n}^{loco}$	81



4. Experiment Result

➤ **Case 2:** $\eta_{r,n}^{loco}$, $\eta_{r,n}^{crew}$, $\eta_{r,n}^{order} = 50\%$

- Solution results and compare with case 1

Item	Value of case1	Value of case2
objective function	104493551	52788091
average delay time of each train at its destination station	7514	3763
maximum delay time of each train at its destination station	17916	9249
average delay time of all trains at all stations	6917	3395
maximum delay time of all trains at all stations	17916	9249
Last actual arrival time	9/20/2017 9:43 AM	9/14/2017 9:22 AM



4. Experiment Result

➤ Conclusion

- Delay for each train increases significantly under 90% confidence level for lognormal distribution of dwell time.
- The core issues are the work order and crew change.
- A kind of single-track railway scheduling problem results in the tight utilization of industrial spurs to enlarge the delay
- Crew change may occupy the main track for a long time in stations without siding and yard.
- Need to schedule the work order and crew change in reasonable stations.





Thanks for your attention!

