Real-time High Speed Train Rescheduling in Case of A Partial Segment Blockage

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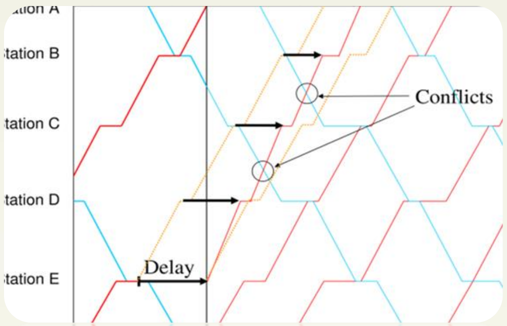
Outline

Introduction

Research Significance

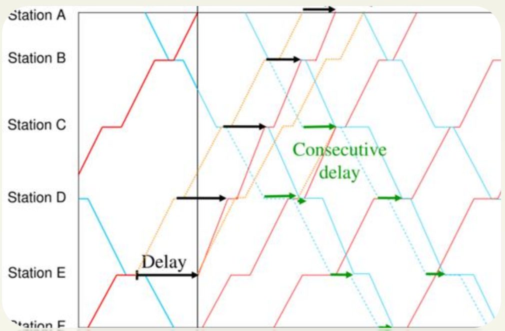


Factors

- External and internal factors
- Few previous research

Manually

- Train rescheduling is mainly done by dispatchers



Practical significance

- Real-time train rescheduling is very important in helping dispatchers to reschedule trains

Introduction

Research content

This paper focuses on high speed train rescheduling on a long high speed line with a dense traffic in a partial segment blockage.

The main contributions are as follow:

- Reschedule trains on a long high speed line with a dense traffic and a non-periodic timetable.
- Various types of trains and trains with different stopping patterns.
- Trains are allowed to arrive earlier than scheduled.
- No anticipation on the occurrence and the duration of the disruption is priori unknown.

Problem description

track layout and train types

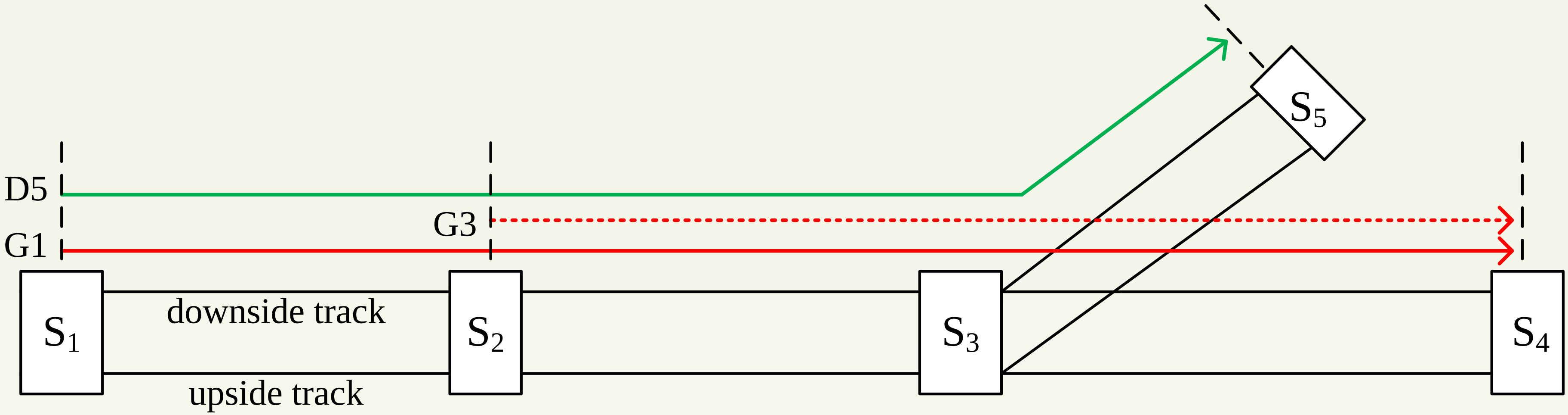


Fig.1 Track layout and various types of trains

Problem description

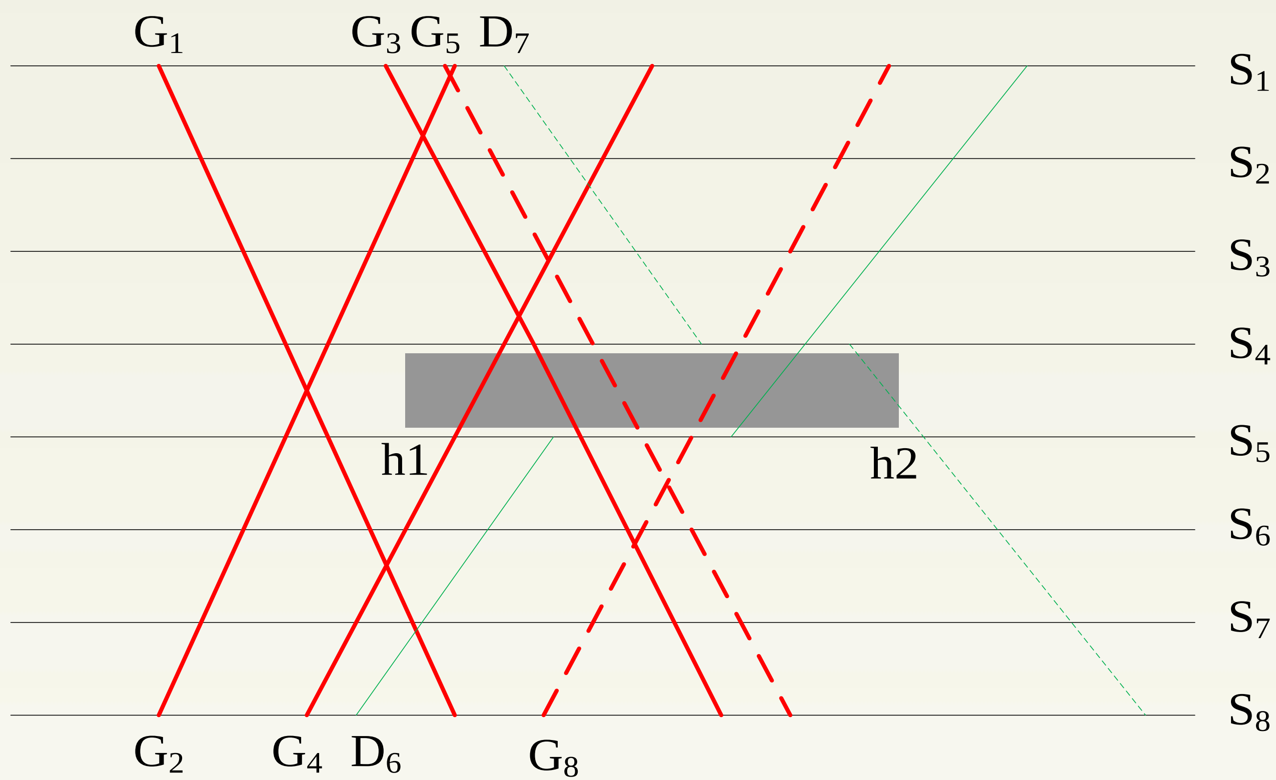


Fig. 2 A disposition timetable in a partial blockage for small instance

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Model formulation

Assumptions:

- Each track of the double-track lines is a bidirectional line in the perspective of technology.
- Both tracks of the main line is connected with each siding in each station
- Upside (downside) trains are only allowed to use upside (downside) sidings.
- Trains run as scheduled before the disruption.
- Trains can continue their journeys if they have already entered the disrupted segment at the start of the disruption.

Model formulation

Basic model

Objective:

min: train cancelation penalty +
total weighted train deviation
(earliness and tardiness)

Min: $$\sum_{t\in T}\gamma_t y_t + \sum_{e\in E}\mu_e^+ d_e^+ + \sum_{e\in E^{arr}}\mu_e^- d_e^-$$

Subject to:

(1) The domain of events (move canceled trains)

$$2M_1 y_{t_e} - M_1 \le x_e - q_e \le M_1 \quad \forall e\in E, t_e \in T$$

Model formulation

Basic model

Subject to:

(2) trains cannot depart earlier

$$x_e \geq q_e \quad \forall e \in E^{dep}$$

(3) deviation of train events

$$d_e^+ \geq x_e - q_e - M_1 y_{t_e} \quad \forall e \in E, t_e \in T$$

$$d_e^- \geq q_e - x_e \quad \forall e \in E^{arr}$$

(4) deviation of train events cannot exceed maximum deviation

$$d_e^- \leq D \quad \forall e \in E^{arr}$$

$$d_e^+ \leq D \quad \forall e \in E$$

Model formulation

Basic model

Subject to:

(5) run as scheduled before disruption

$$x_e = q_e \quad \forall e \in E : q_e \leq H_{dis}^{start}$$

(6) running train cannot be canceled

$$y_{t_e} = 0 \quad \forall t_e \in T, e \in E_{s_{t_e}^o}^{dep} : q_e \leq H_{dis}^{start}$$

(7) the domain of variables

$$y_t \in \{0,1\} \quad \forall t \in T$$

$$x_e, d_e^+, d_e^- \geq 0 \quad \forall e \in E$$

Additional constraints

- Single train precedence constraints

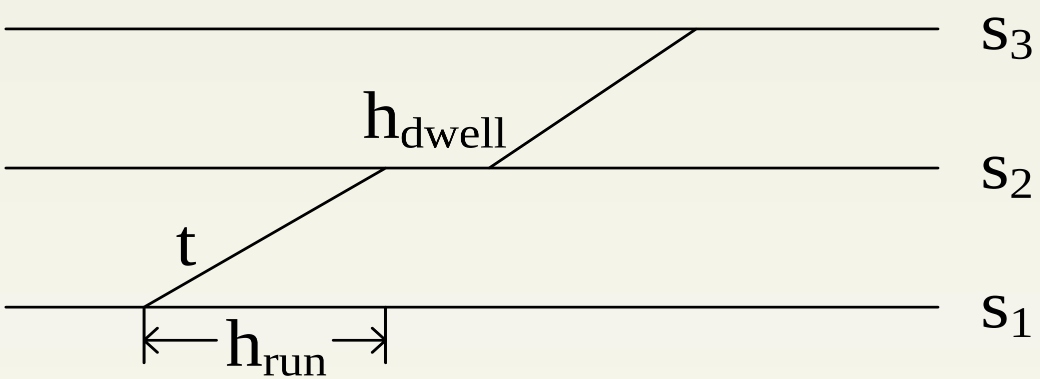

Fig. 3 Single train running graph

$$x_f - x_e \geq L_a \quad \forall a = (e, f) \in A_{train}$$

Additional constraints

- Headway constraints between trains

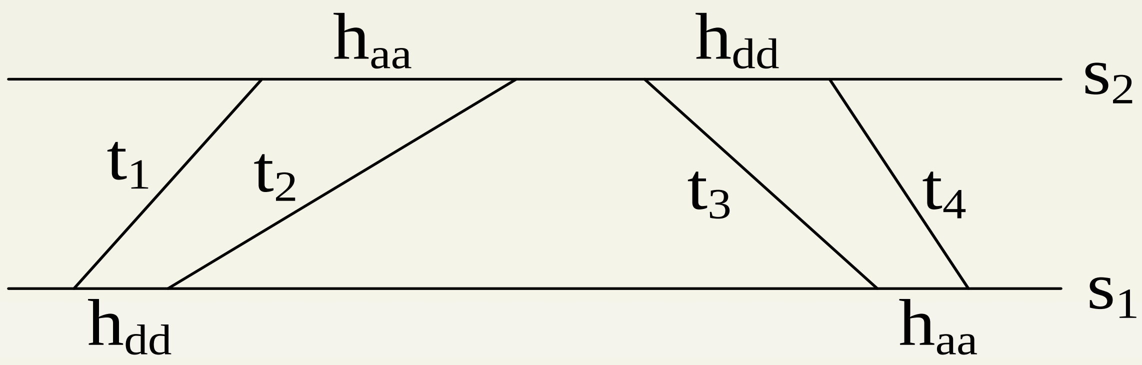

Fig. 4 Headway between trains in the same direction

$$\lambda_a + \lambda_{a'} = 1 \quad \forall a = (e, f) \in A_{\text{head}}^{track,1} \wedge a' = (f, e) \in A_{\text{head}}^{track,1}$$

$$x_f - x_e + M_2(1 - \lambda_a) \geq L_a \quad \forall a = (e, f) \in A_{\text{head}}^{track,1}$$

Additional constraints

- Overtaking constraints

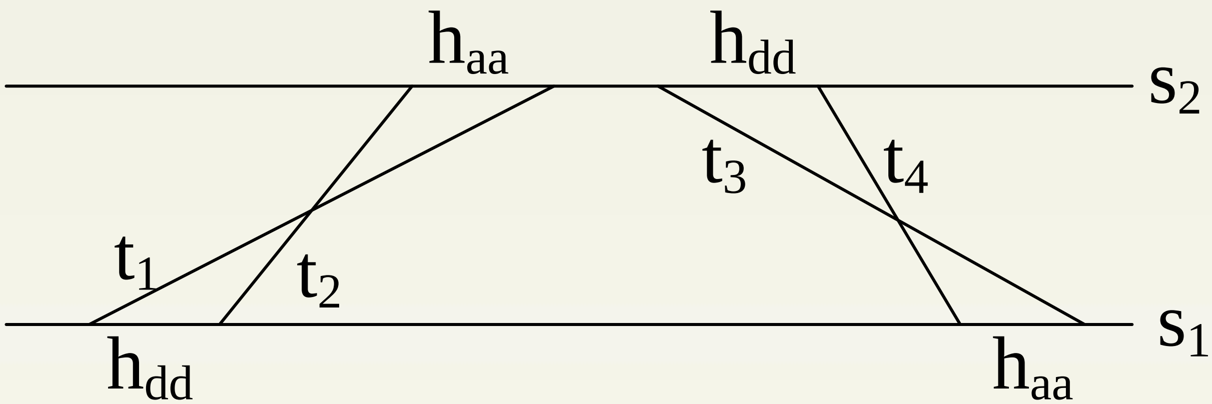

Fig. 5 Overtaking between trains

Note: Only trains in the same direction may overtake each other

$$\lambda_a = \lambda_{a'} \quad \forall (a, a') \in B$$

Additional constraints

➢Headway constraints between trains (opposite direction)

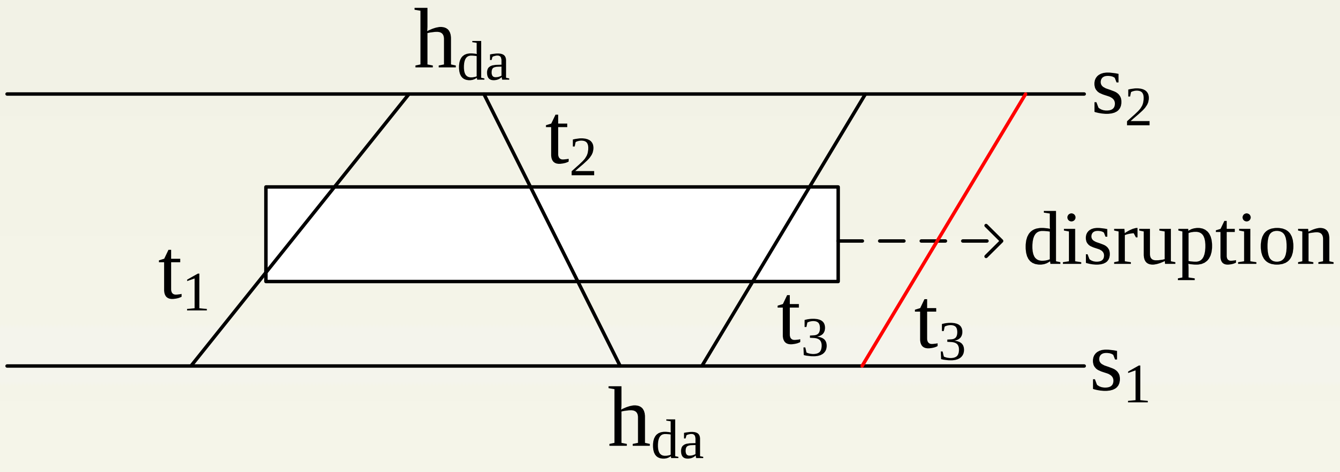

Fig. 6 Headway between trains in opposite directions

Which disrupted train needs to run on the reverse track in the blocked segment is related to the train rescheduling results. (Fig.6: upside track is blocked)

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Additional constraints

➢ Headway constraints between trains(opposite direction)

Define binary variable:

$$\chi_e^d = \begin{cases} 1 & \text{if train } t_e \text{ departs from station } s_e \text{ before the disruption ends} \\ 0 & \text{otherwise} \end{cases}$$

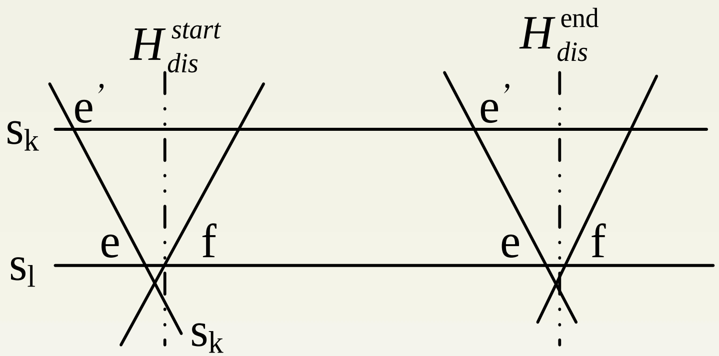
$$H_{dis}^{end} \times (1 - \chi_e^d) < x_e \le H_{dis}^{end} + (1 - \chi_e^d) \times M_2$$

$$x_f - x_e + M_2(1 - \lambda_a) + M_2(1 - \chi_{e_1}^d) \ge L_a \qquad \forall a = (e, f) \in A_{\text{head}}^{track,2}$$

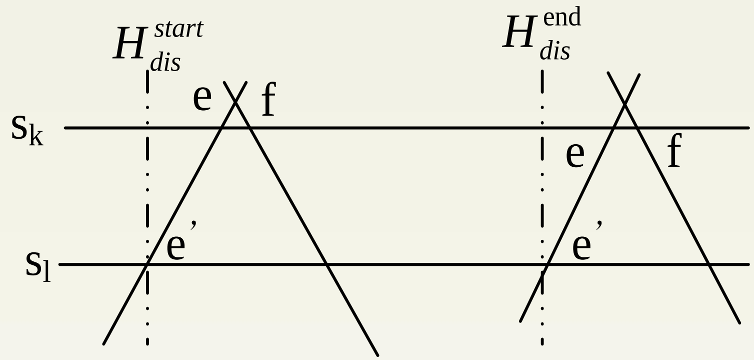
The domains of events differ due to different disruption scenarios and types of trains, show as follow:

Additional constraints

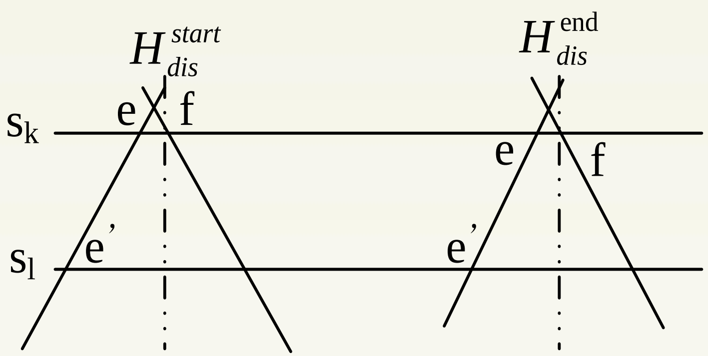
➢ Headway constraints between trains(opposite direction)



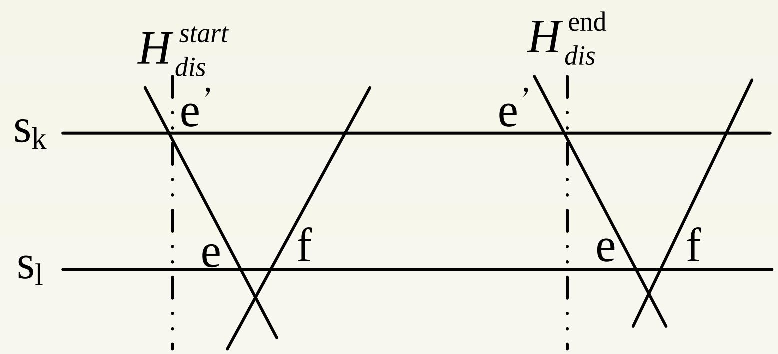
(1) Headway between upside departure-downside arrival



(2) Headway between downside departure-upside arrival



(3) Headway between downside departure-upside arrival



(4) Headway between upside departure-downside arrival

Fig. 7 Headway between trains in opposite directions

Additional constraints

- Station capacity constraints

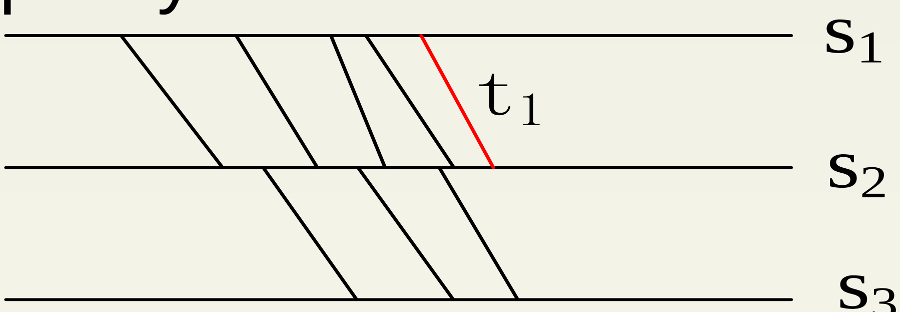


Fig. 8 Graph for trains running in a station

Define binary variable:

$$\varphi_a = \begin{cases} 1 & \text{if train } t_e \text{ departs from station } s \text{ before train } t_f \text{ arrives there} \\ 0 & \text{otherwise} \end{cases}$$

$$\sum_{a=(e,f)\in A^1_{s,f}} \lambda_a - \sum_{a=(e,f)\in A^2_{s,f}} \varphi_a \le C_s^{down} - 1 \quad \forall s \in S^m,\ f \in E_s^{arr} : q_f \ge H_{dis}^{start} \wedge t_f \in T^{down}$$

$$\sum_{a=(e,f)\in A^1_{s,f}} \lambda_a - \sum_{a=(e,f)\in A^2_{s,f}} \varphi_a \le C_s^{up} - 1 \quad \forall s \in S^m,\ f \in E_s^{arr} : q_f \ge H_{dis}^{start} \wedge t_f \in T^{up}$$

$$x_f - x_e + M_2(1-\varphi_a) \ge L_a \qquad \forall a = (e,f) \in A_{station}$$

Additional constraints

- Train balance constraints

The number of canceled trains of the same type in each direction should be more or less equal.

$$\sum_{t \in p} y_t - \sum_{t \in p'} y_t \leq \delta \quad \forall t \in T$$

$$\sum_{t \in p'} y_t - \sum_{t \in p} y_t \leq \delta \quad \forall t \in T$$

Rolling horizon approach

Real-time train rescheduling is complicated:

- Long high speed line
- Large number of trains
- Limited computation time

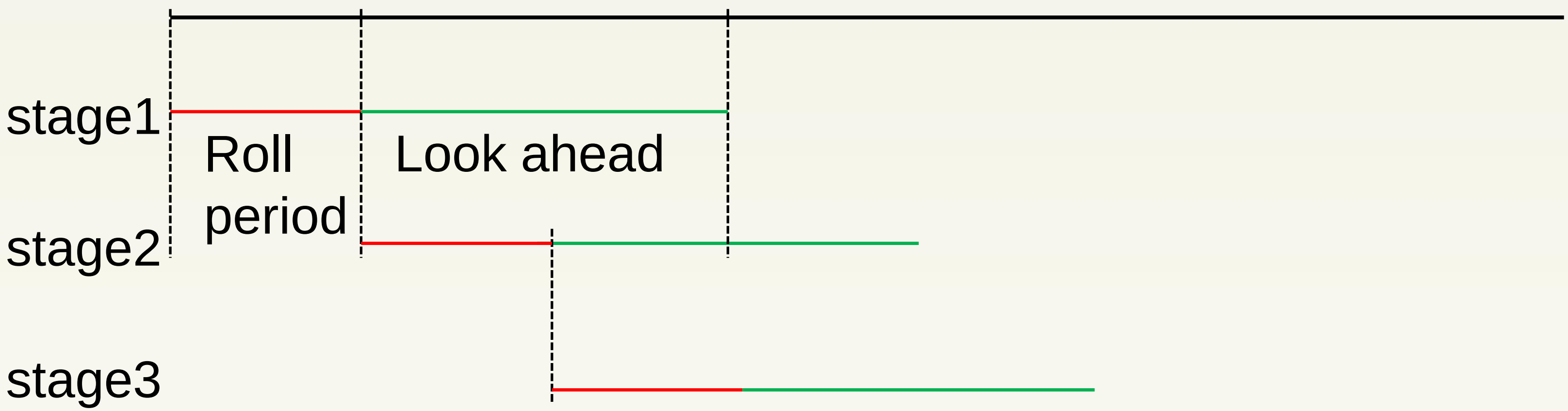
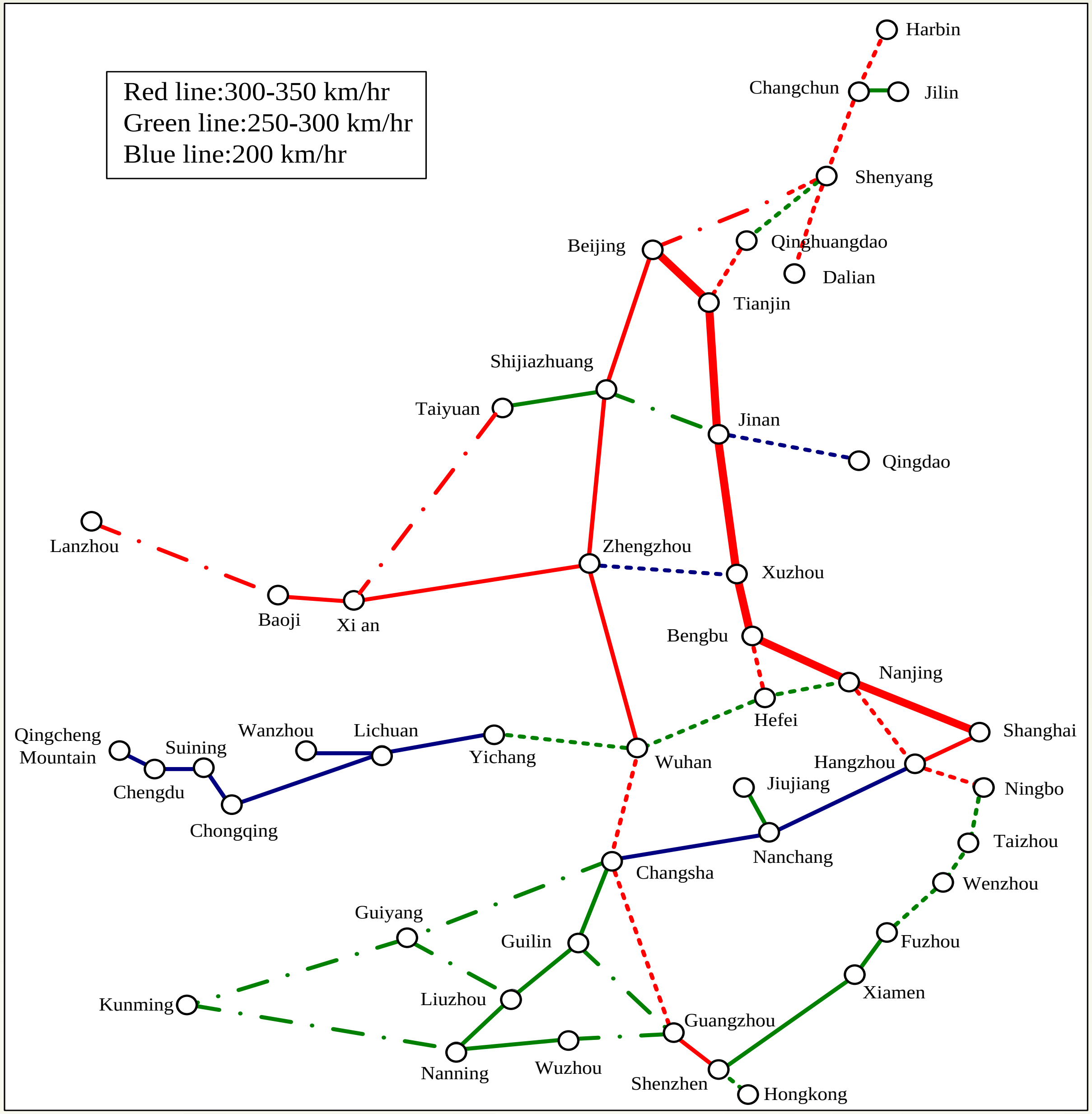


Fig. 9 Rolling horizon framework

Experiment setting

The Beijing-Shanghai high speed railway and other related high speed railways.

90 upside and 90 downside trains



Experiment setting

Tab. 1 Assumed disruption scenarios

Scenarios	Occurrence time	Location	duration	Disrupted track
1	10:00	5	60/90/120	Downside track
2	13:00	11	60/90/120	Upside track
3	13:00	11	60/90/120	Downside track
4	17:00	16	60/90/120	Upside track

Tab. 2 Disruption instances with updating information

Instances	Scenarios	Duration time updates
1	1	{10:00, $H_{10:00\text{-}11:30}$}, {11:00, $H_{10:00\text{-}12:00}$}
2	2	{13:00, $H_{13:00\text{-}14:00}$}, {13:30, $H_{13:00\text{-}15:00}$}
3	3	{13:00, $H_{13:00\text{-}14:30}$}, {14:00, $H_{13:00\text{-}15:00}$}
4	4	{17:00, $H_{17:00\text{-}18:30}$}, {17:30, $H_{17:00\text{-}19:00}$}

Experiment results

*Instance**	horizon (min)	Obj.	TD (min)	Cancel	Time(s)	Gap(%)	Recover
$(10, 5, 60)^2$	180	3562	928	0	70	0	
	690	231	953	0	88	0	13:07
$(10, 5, 90)^2$	180	5353	1377	0	245	0	
	690	1081	1540	0	75	0	13:56
$(10, 5, 120)^2$	130	5674	1485	0	300	13.99	
	740	7029	2714	0	193	0	14:51
$(13, 11, 60)^2$	130	4581	1177	0	80	0	
	560	1789	1364	0	47	0	15:56
$(13, 11, 90)^2$	130	8644	2227	0	300	14.43	
	560	8258	3502	0	145	0	18:01
$(13, 11, 120)^2$	130	10043	2635	0	300	14.72	
	560	13331	5013	0	95	0	18:30
$(13, 11, 60)^2$	130	5044	1410	0	95	0	
	560	2864	2048	0	26	0	19:06
$(13, 11, 90)^2$	130	8089	2088	0	300	12.32	
	560	6418	2980	0	50	0	17:55
$(13, 11, 120)^2$	130	10117	2655	0	300	18.61	
	560	13573	5086	0	117	0	18:32
$(17, 16, 60)^1$	420	1082	294	0	20	0	19:22
$(17, 16, 90)^1$	420	1510	403	0	30	0	18:54
$(17, 16, 120)^1$	420	2112	560	0	64	0	20:05

Experiment results

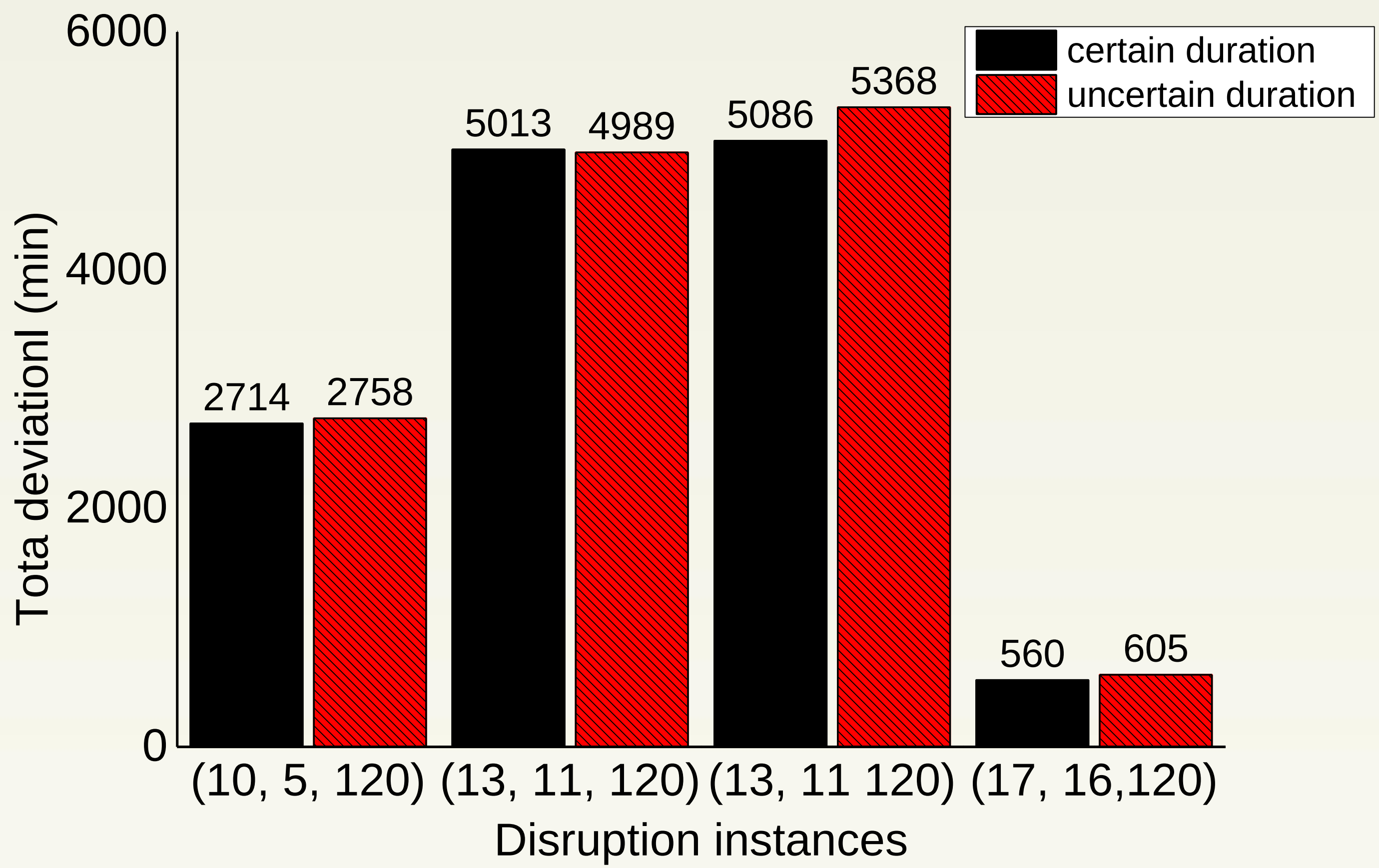


Fig. 10 Total deviation for disruption instances under certain and uncertain duration of disruptions

Experiment results

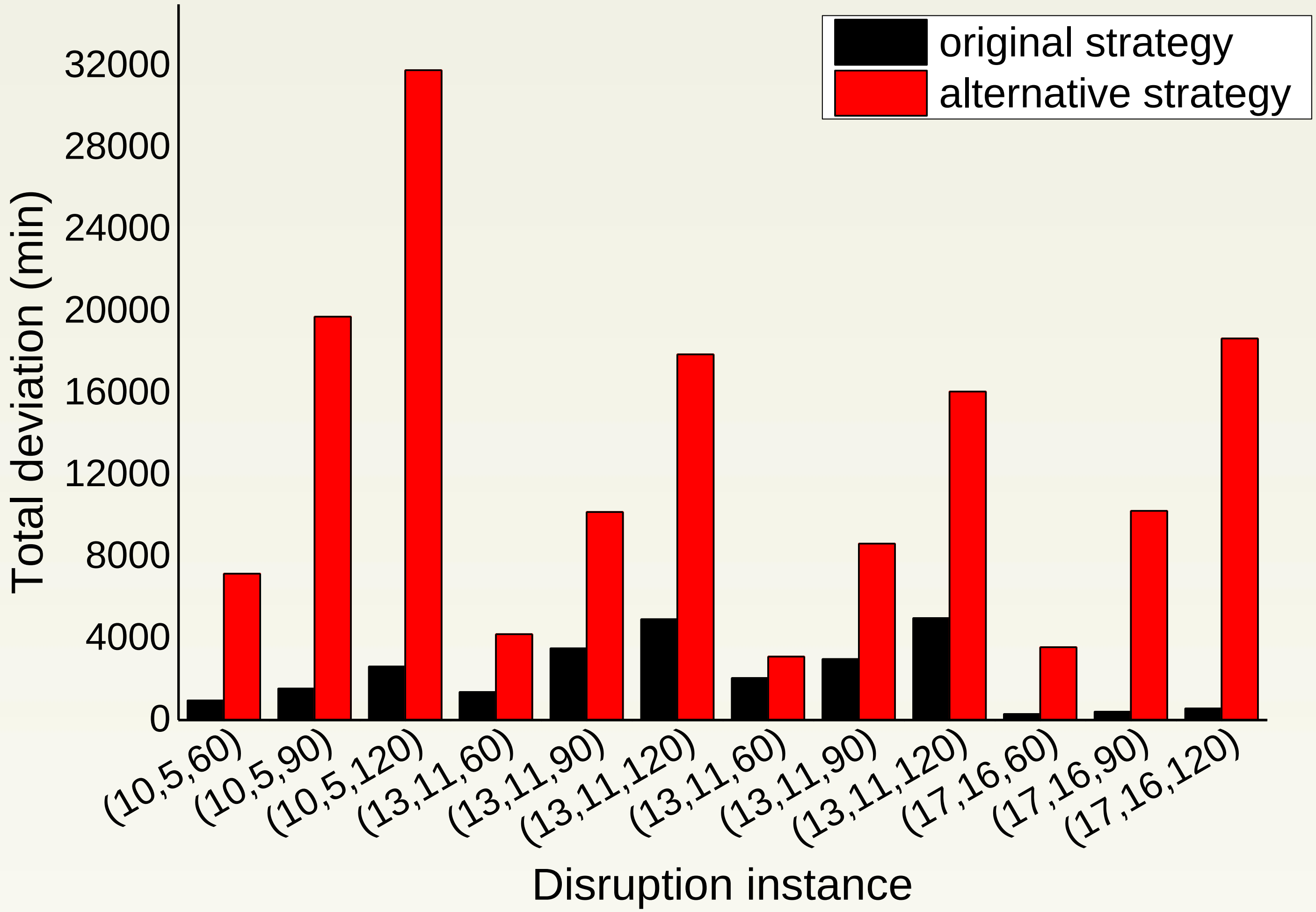


Fig. 11 Total deviations for two train rescheduling strategies

Conclusion

- A mixed integer programming model is formulated to reschedule trains in a partial segment blockage.
- Various types of trains and trains with different stopping patterns are investigated.
- Uncertain duration of the disruption is handled by updating the information.
- Two important train rescheduling strategies are explicitly compared.
- A large real-world high speed railway case in China is tested.

THANK YOU

for your attention!

Any questions