Adjusting a Railway Timetable in case of Partial or Complete Blockades

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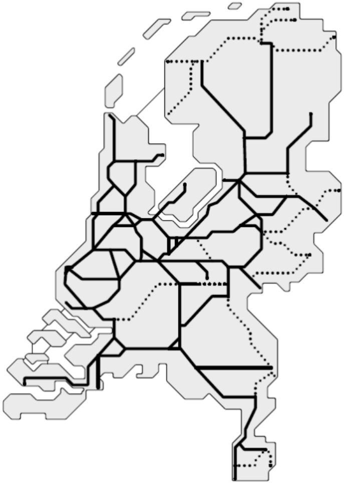
Outline

Dutch railway system

- Dense railway system.
- Cyclic timetable with a cycle time of one hour.
- Long distance and regional trains are operated.
- On a normal weekday NS operates 5,200 trains and serves 1.2 million passengers.



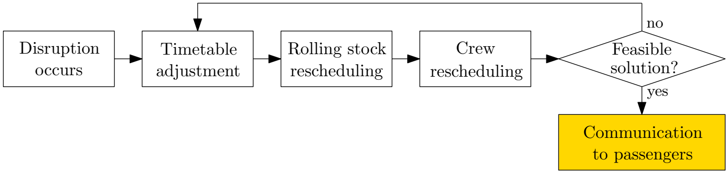
Introduction

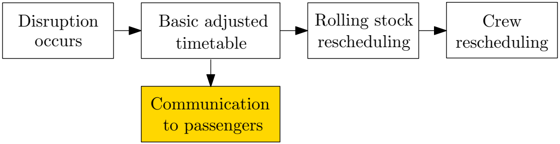
- Unexpected disruptions happen on average three times a day.
- The timetable, rolling stock schedule and crew roster are not feasible anymore and need to be adjusted.
- We focus on large disruptions: *partial* or *complete blockades*.
- Given an infrastructure situation and a forecast of the characteristics of the disruption, a rescheduled *disposition timetable* needs to be determined.
- Limited time available to calculate a solution.


Disruption management process

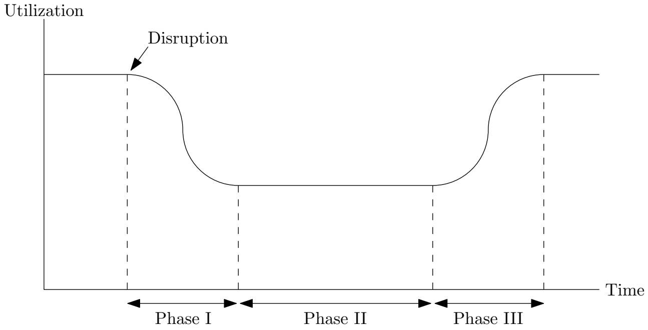
- The three main subproblems of the disruption process are solved consecutively:
  1. Timetable adjustment
  2. Rolling stock rescheduling
  3. Crew rescheduling
- The problems are interdependent but solving them simultaneously is too time consuming.
- We aim to determine a basic disposition timetable such that the probability that feasible solutions to the rolling stock and crew rescheduling problems do exist is high, without explicitly taking these problems into account.

Disruption management process





Disruption process



- We focus on the second phase, in which the disposition timetable is operated.
- Currently, static disruption scenarios are used to adjust the timetable. These scenarios are not optimal for all situations.

Problem description

- We define a core problem and limit the problem area and the time horizon.
- The disruption measures we include are:
  - Cancel trains
  - Delay trains
  - Reverse trains at stations before the blockade
- Limited track capacity.
- Limited number of rolling stock units available at the moment the disruption occurs.
- We want to obtain a cyclic disposition timetable.

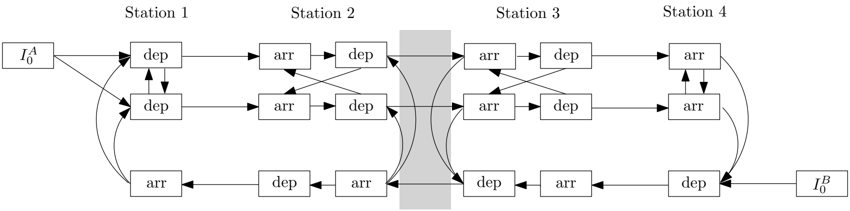
Problem description

Weighted objective function:

1. Main objective is to maximize the service level offered to the passengers:
   a. Minimize the number of canceled trains
   b. Minimize train delays
2. Balance the number of trains in each direction.
3. Distribute the operated trains evenly over time.

Partial blockade

- One track of a two-track segment is blocked.
- Decide which trains are canceled and about the delays of the non-canceled trains.
- Formulation based on an event-activity network.
  - Arrival and departure events
  - Train activities, headway activities and inventory activities



Partial blockade

Variables of the model:

$$y_v = \begin{cases} 1 & \text{if trains } v \text{ are canceled;} \\ 0 & \text{otherwise.} \end{cases}$$

x_e Time of event e in the disposition timetable.

$$z_a = \begin{cases} 1 & \text{if activity } a \text{ is canceled;} \\ 0 & \text{otherwise.} \end{cases}$$

δ Absolute difference between the number of canceled trains in each direction.

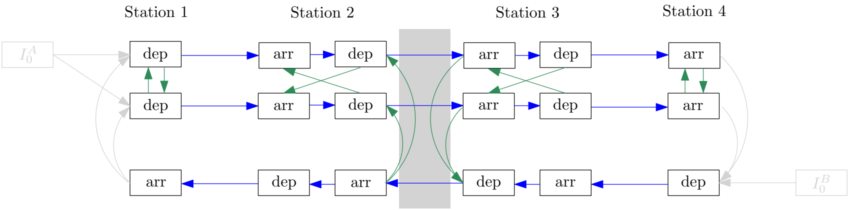
μ Maximum time between two operated trains in the same direction.

Partial blockade

$$\min \alpha_1 \sum_{v \in V} y_v + \alpha_2 \sum_{e \in E} (x_e - q_e) + \alpha_3 \delta + \alpha_4 \mu \tag{1}$$

$$\begin{aligned}
x_e - q_e &\geq 0 && \forall e \in E && (2)\\
x_e - q_e &\leq d && \forall e \in E && (3)\\
\left| \sum_{v \in V^A} y_v - \sum_{v \in V^B} y_v \right| &\leq \delta && && (4)\\
x_{\varepsilon_w} - x_{\varepsilon_v} - My_v - My_w - \sum_{\substack{u \in V^A \\ v < u < w}} M(1 - y_u) &\leq \mu && \forall v, w \in V^A && (5)\\
x_{\varepsilon_w} - x_{\varepsilon_v} - My_v - My_w - \sum_{\substack{u \in V^B \\ v < u < w}} M(1 - y_u) &\leq \mu && \forall v, w \in V^B && (6)
\end{aligned}$$

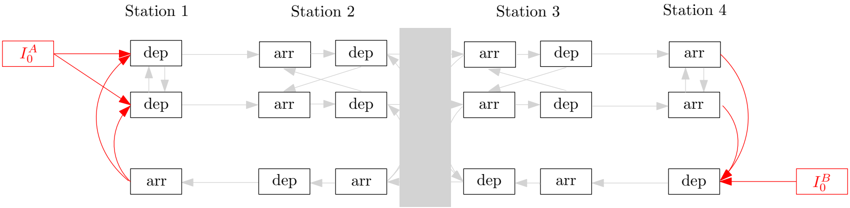
Partial blockade



Constraints for the train activities and headway activities:

$$
\begin{aligned}
x_f - x_e &\geq L_a && \forall a = (e,f) \in A_{train} && (7)\\
x_f - x_e + M(1-\lambda_{ef}) &\geq L_a && \forall a = (e,f) \in A_{head} && (8)\\
\lambda_{ef} + \lambda_{fe} + y_{\pi_e} + y_{\pi_f} &\geq 1 && \forall (e,f) \in A_{head} && (9)
\end{aligned}
$$

Partial blockade



Inventory activities to model the limited number of available rolling stock units at the start of the disruption:

$$\sum_{a \in \eta^{out}(e)} (1 - z_a) \leq I_0 \qquad \forall e = I_0 \tag{10}$$

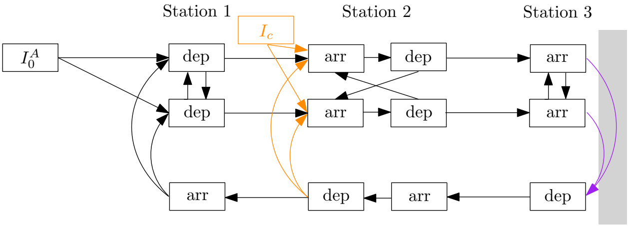
$$\sum_{a \in \eta^{in}(e)} (1 - z_a) = 1 - y_{\pi_e} \qquad \forall e \in E_{orig} \tag{11}$$

$$\sum_{a \in \eta^{out}(e)} (1 - z_a) \leq 1 - y_{\pi_e} \qquad \forall e \in E_{dest} \tag{12}$$

$$x_f - x_e + Mz_a \geq L_a \qquad \forall a = (e, f) \in A_{inv} \tag{13}$$

Complete blockade

- No traffic possible on the blocked segment.
- Solve two models, one for each side of the blockade.
- Turn around activities connect an arriving and a departing train at the blocked segment.
- Capacity activities to model the limited capacity at the turn around station.

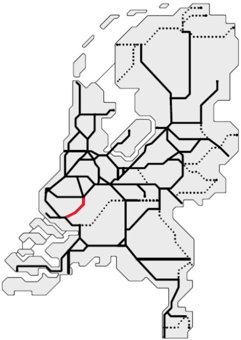


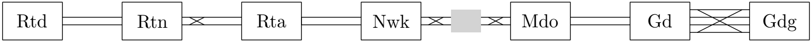
Regular disposition timetable

- High passenger service level can also be defined by regular train connections.
- Only regional trains are operated.
- In both directions trains run two, three or four times per hour at equal time intervals.
- Larger deviations from the normal timetable:
  - More difficult to work with in the integrated solution approach.
  - The impact of the disruption outside the problem area increases.

Results

- Partial and complete blockade between stations Rotterdam and Gouda.
- The disposition timetable needs to be operated from 16:00h to 18:00h on a weekday.





Partial blockade

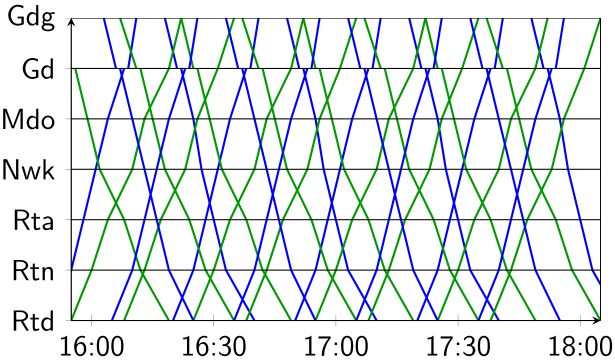


Figure 1: Normal timetable

Partial blockade

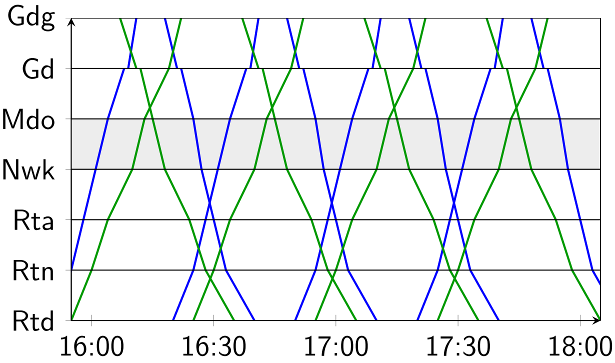


Figure 2: Disposition timetable disruption scenario.

Partial blockade

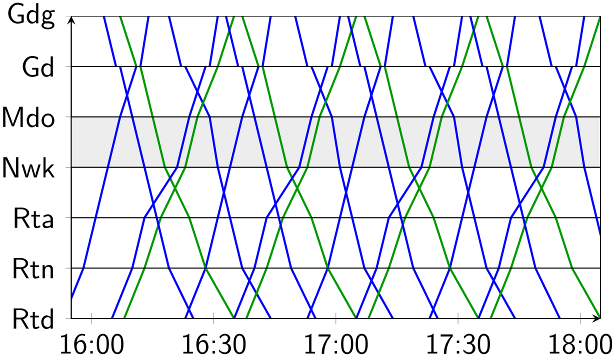


Figure 3: Disposition timetable, maximum five minutes delays.

Partial blockade

Table 1: Disposition timetables for different maximum delay values.

Max delay	Trains per hour	Delayed events (%)	Average delay	Max interval	Objective value LP	Objective value IP	Time (s)
0	8	0	0	26	8.35	9.30	<1
1	8	17	1	25	5.54	9.25	<1
2	8	19	1.3	24	3.64	9.21	<1
3	8	14	2.1	23	2.20	9.16	<1
4	10	14	1	16	1.31	6.85	<1
5	12	15	2.4	16	0.87	6.50	<1
10	14	32	6.2	13	0.56	2.92	5.8
15	16	46	6.5	18	0.50	1.30	5.9

Partial blockade

Table 2: Disposition timetables for different start inventories.

Start inventory		Trains	Max	Objective	
Rtd	Gdg	per hour	interval	value IP	Time (s)
4	2	8	26	9.3	<1
3	2	8	26	9.3	<1
2	2	6	26	11.3	<1
1	2	4	34	13.7	<1
2	1	4	34	13.7	<1

Partial blockade

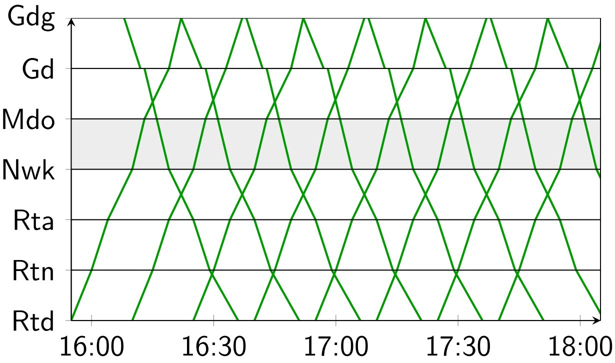


Figure 4: Regular disposition timetable.

Complete blockade

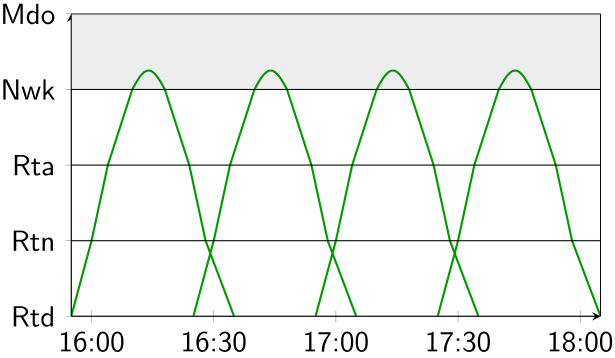


Figure 5: Disposition timetable disruption scenario.

Complete blockade

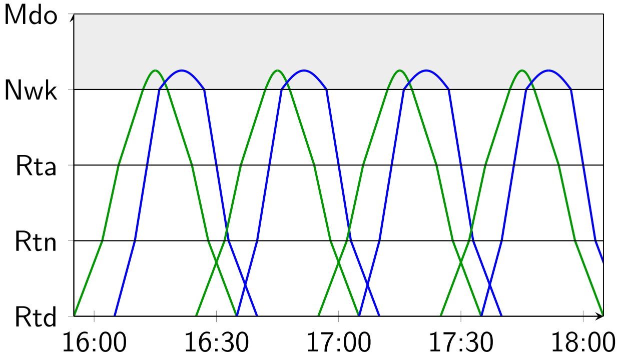


Figure 6: Disposition timetable, maximum one minute delay.

Complete blockade

Table 3: Disposition timetables for different maximum delay values.

Max delay	Trains per hour	Delayed events (%)	Average delay	Max interval	Objective value LP	Objective value IP	Time (s)
0	6	0	0	25	9.10	11.25	<1
1	8	6	1	24	7.45	9.21	<1
2	8	6	2	23	6.94	9.17	<1
3	8	6	3	22	6.53	9.13	<1
4	8	6	4	21	6.20	9.10	<1
5	8	64	2.2	19	5.99	9.06	<1
10	10	31	5.6	14	3.61	7.00	<1
15	10	31	4.9	14	2.71	6.96	<1

Complete blockade

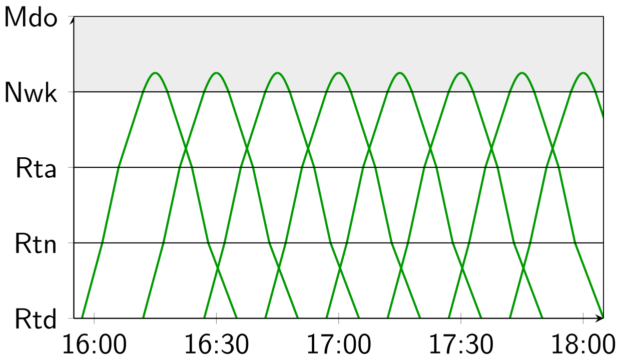


Figure 7: Regular disposition timetable.

Conclusions

- Adjust a railway timetable in case of partial or complete blockades.
- Results provide insight into possible disposition timetables.
- Balance between the number of operated trains and the train delays.
- Short computation times acceptable in realtime.

Further research

- Extend the model to cover also the first and third phase of the disruption process.
- Further integration of timetable adjustment, rolling stock rescheduling and crew rescheduling.
- Include other disruption measures, e.g. rerouting trains.