# Berliner Digitaler Bahnbetrieb (BerDiBa)

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TU Berlin (MDT)
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## Project

Motivation:

- Ensuring reliable, cost-efficient, and secure public transport
- Reduction of the emission of greenhouse gases and pollutants
- Increase quality of life in cities and metropolitan areas
- The Berlin Mobility Act (Berliner Mobilitätsgesetz) from 2018

Project goal:

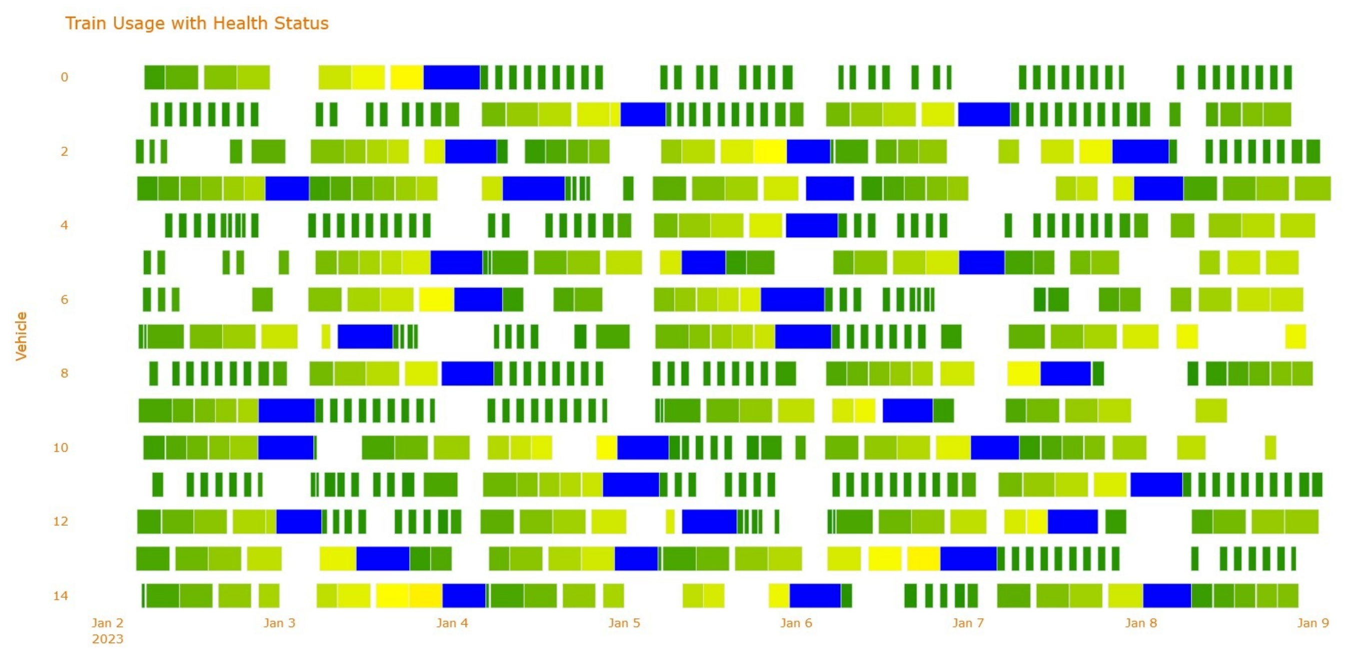
- Establishment of digital and holistic twins
- Development and efficient implementation of railway transportation
- Autonomous driving and ultimately fully automated operation

Our task:

- Assign vehicles to train services, automatically schedule the necessary maintenance operations and optimize the utilization of trains
- Incorporate predictive maintenance into rolling stock rotation planning (RSRP)

## RSRP with Predictive Maintenance

- Given: Railway network, timetable, vehicles with individual health states, estimations of degradation caused by trips
- Goals: Rolling stock rotations operating all trips, schedule maintenance based on the predicted health states




Example for vehicle schedules showing their health state in green to red and maintenance activities in blue.

## Graph Model

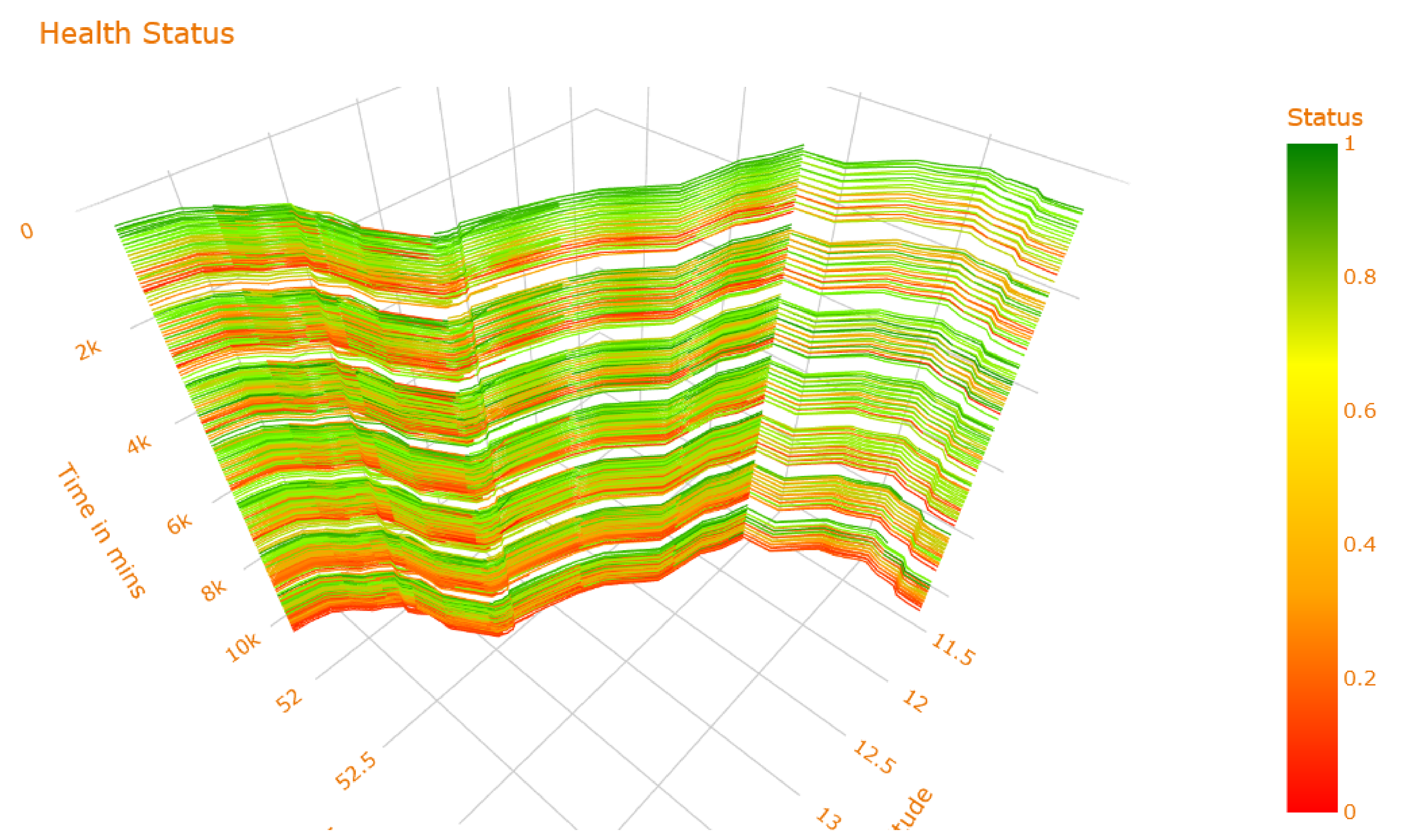
- Arcs represent the trips, deadheads, waiting, and maintenance
- Nodes correspond to the arrival or departure at a location
- Costs of trip arcs depend on their failure probabilities
- Finite set of values $\mathscr{D}$ containing the parameters of the nodes, i.e., each node exists for each value of $\mathscr{D}$
  - $\rightarrow$ The graph has different layers depending on $\mathscr{D}$
  - $\rightarrow$ Arcs between layers are altering the parameters

Assumptions:

- PDFs of health states belong to a parametric family
- Degradation functions of trips are monotonic increasing and Lipschitz
- Failure probability is monotonic and Lipschitz w.r.t. the parameters

Solution:

- Graph approximates the original problem
- Granularity of $\mathscr{D}$ determines the accuracy of the approximation
- Solution for the approximate problem is given by a cost-minimal set of paths covering exactly one arc corresponding to each trip



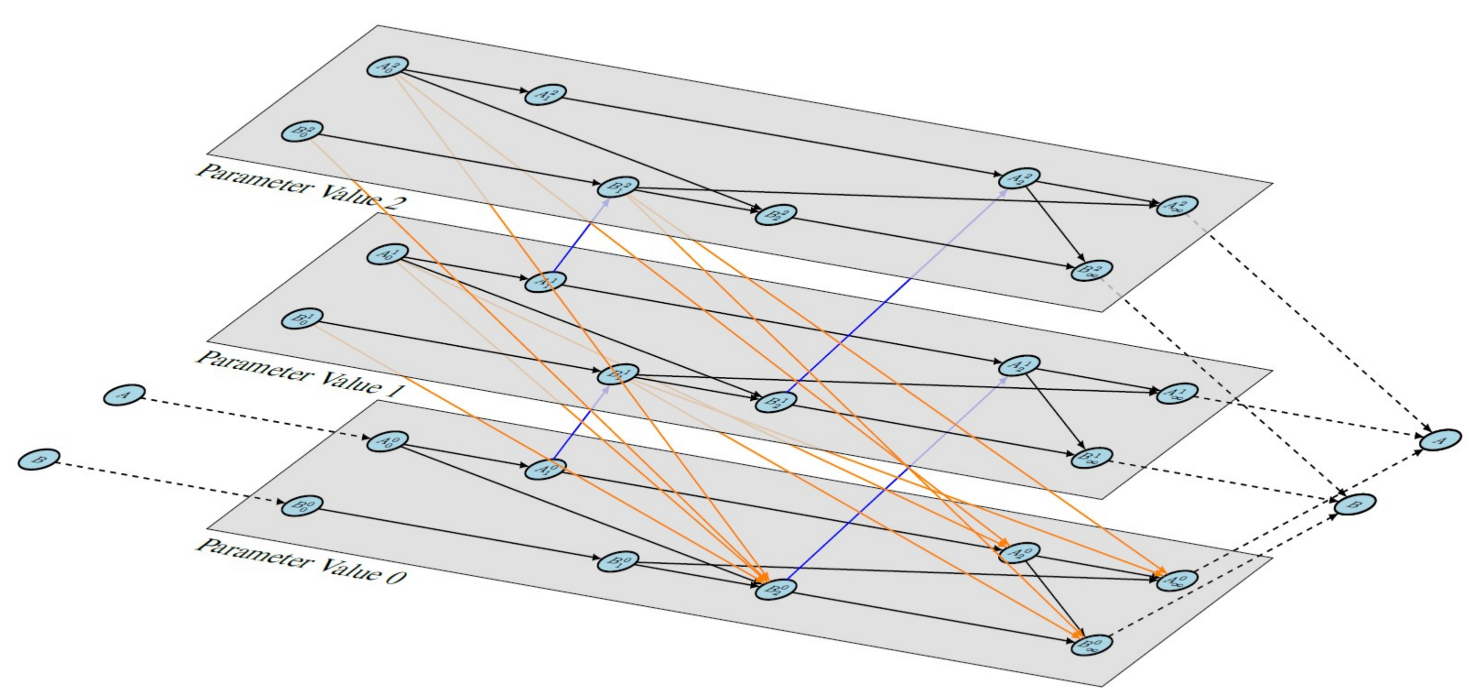

Example for a time-expanded rotation plan showing the health states of the vehicles.

## Solution Approach

- A solution to the approximate problem can be determined by solving the following integer program (IP) formulation:

$$
\begin{aligned}
\min \; & \sum_{a\in A} c_a x_a \\
\text{s.t.} \; & \sum_{a\in A(t)} x_a = 1 && \forall t \in T \\
& \sum_{a\in\delta^+(v)} x_a = \sum_{a\in\delta^-(v)} x_v && \forall v \in V \\
& x_a \in \mathbb{Z}_{\geq 0} && \forall a \in A
\end{aligned}
$$

- Refining $\mathscr{D}$ gives rise to closer approximations of the original problem
- IP-based heuristic: Refine $\mathscr{D}$ randomly
- Iterative refinement approach:
  1. Choose $\mathscr{D}$ randomly or evenly spaced
  2. Determine the corresponding graph and solve the IP
  3. Refine node-wise around parameter values of nodes contained in the resulting paths
  4. Go to 2 and repeat




Example for a parameter-expanded event-graph. Here, deadheads and waiting arcs are black, maintenance arcs are orange, and trip arcs are blue.

## Funding

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