Prediction of train delay propagation in real-time

Thomas Spanninger
IVT – Transport Systems

Agenda

1. Group of Transport Systems

2. Research Project: DADA

3. Prediction of train delays

4. Markov Chain Models in Application

IVT – Transport Systems

Prof. Francesco Corman

Railway traffic control prediction & optimization



Railway timetable optimization

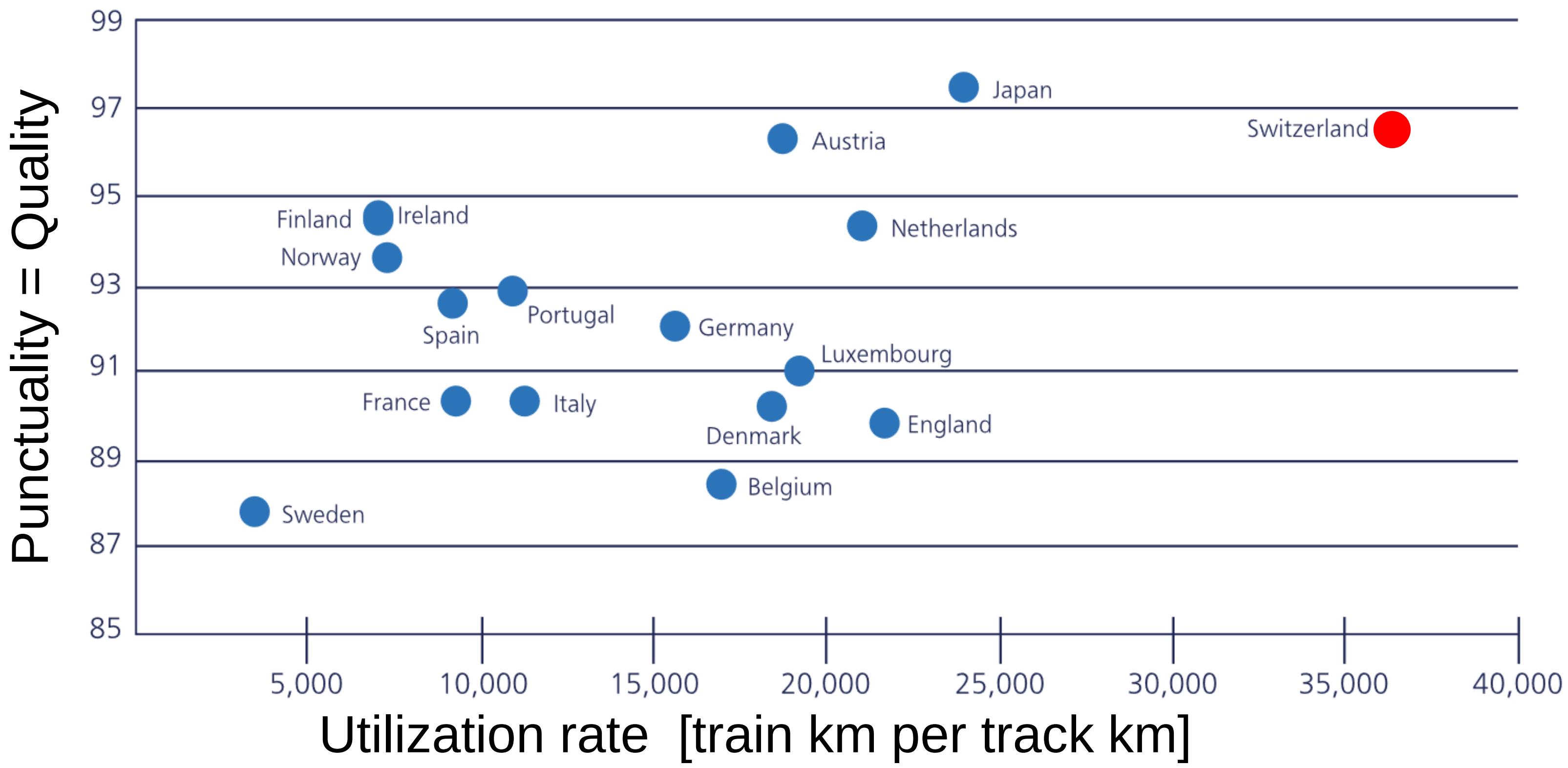

Passenger oriented railway traffic optimization


Track maintenance scheduling


Energy efficient driving, dynamic coupling

Passenger route choice modelling

Optimizing Swiss railway operations?



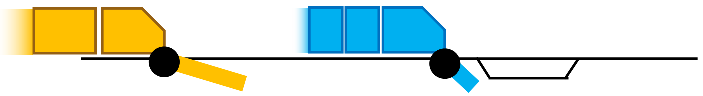
[Federal Office for Spatial Development ARE OFDT, Perspective 2040];[Dutch Railways NS, 2018]

DADA

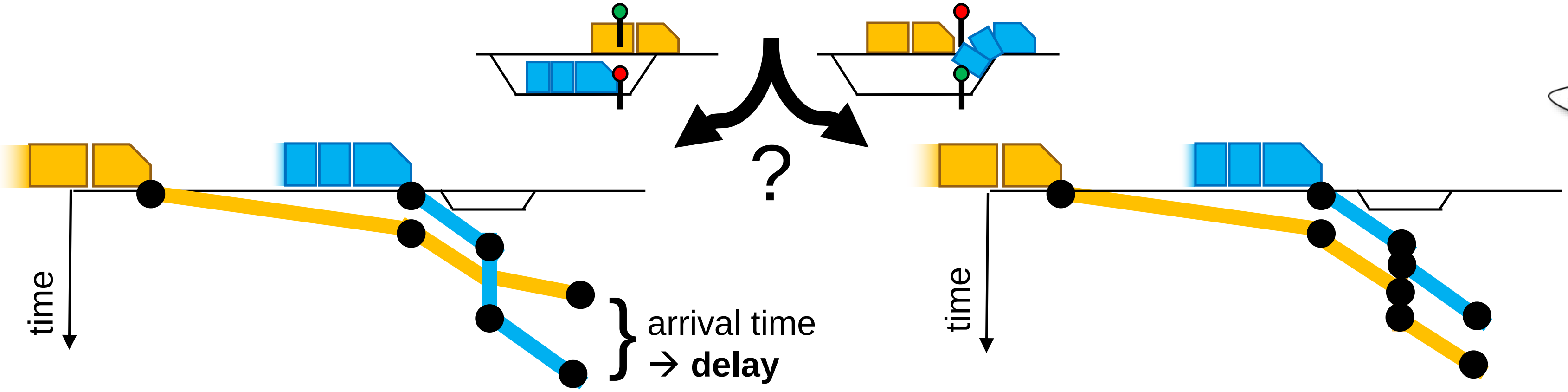
Dynamic data driven Approaches for stochastic Delay propagation Avoidance in railways

- **Increase performance** of railway systems (capacity and delays) by developing intelligent real-time **railway traffic control** approaches, which explicitly consider **uncertainty and variability** in operations

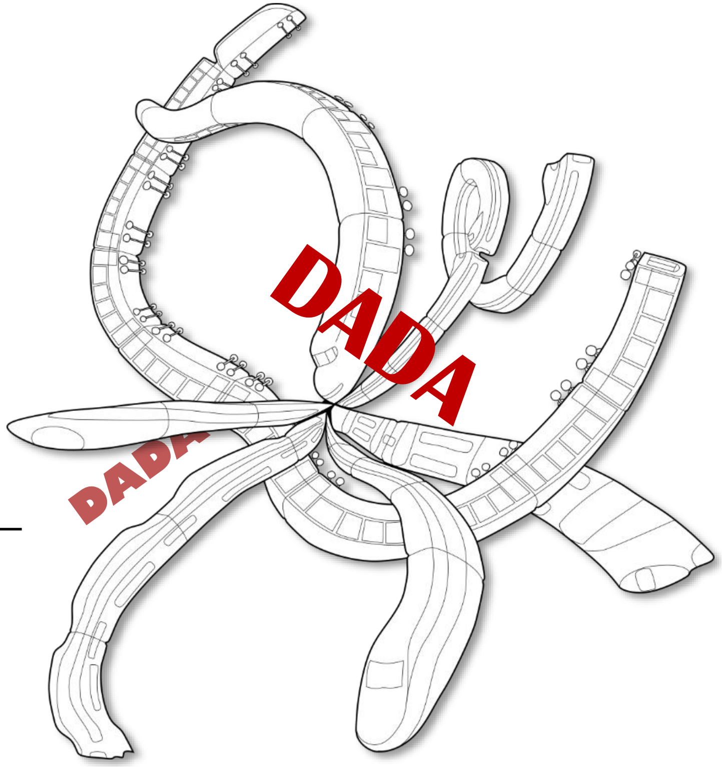
Based on a current network **state**,



determine traffic **control actions** (retiming; **reordering,** rerouting, cancelling,…)
e.g. should the yellow train overtake the blue?

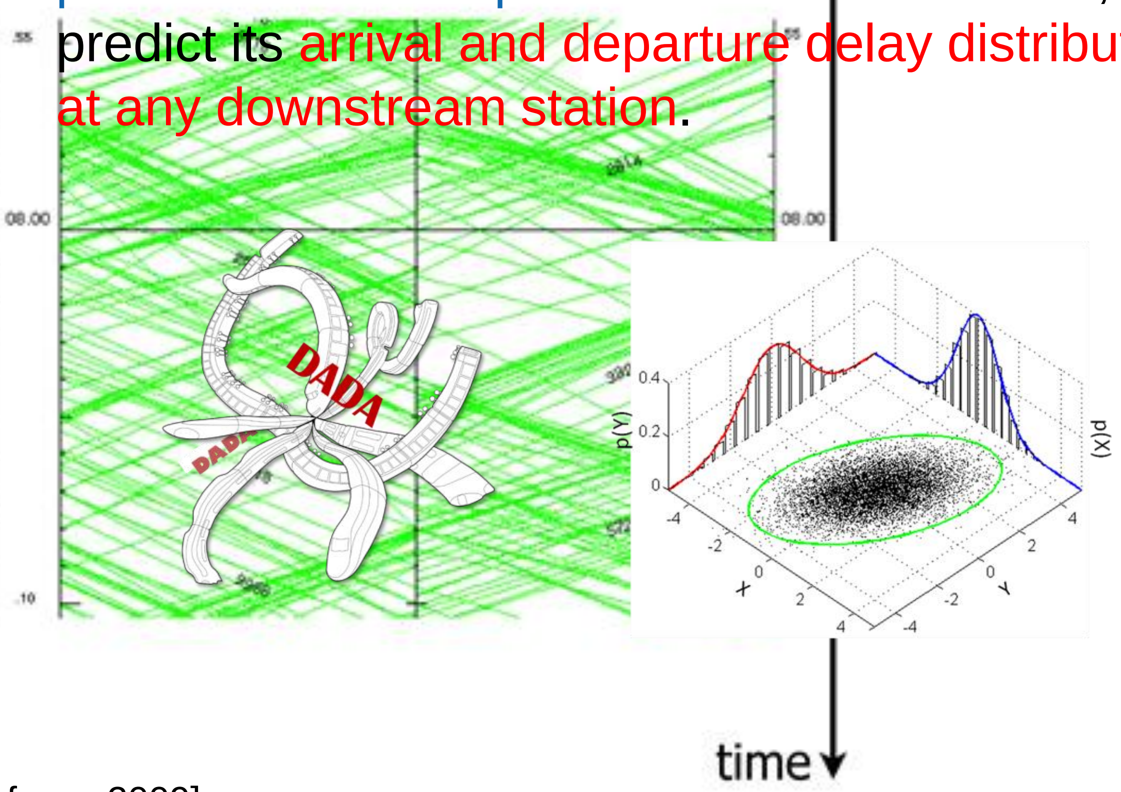


which proactively reduce **delays** and delay propagation



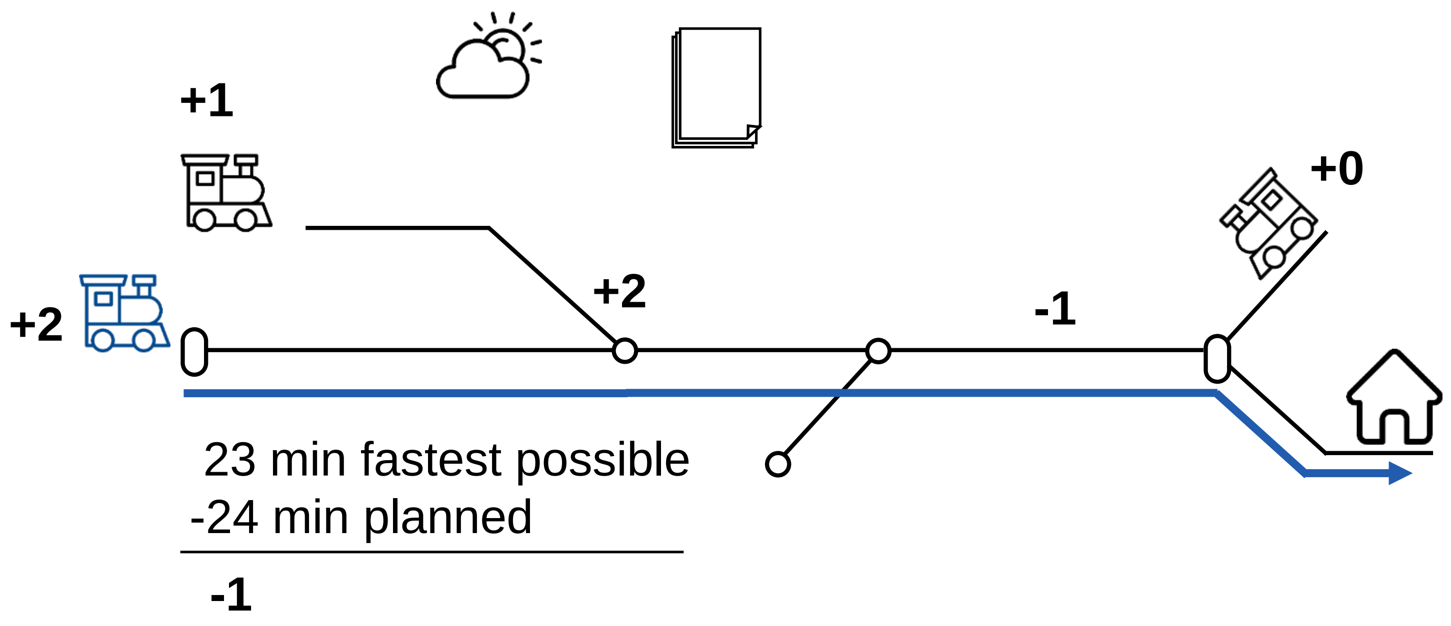
Predicting train delays
A matter of handling uncertainty

Given a train, its timetable, and a set of past arrival and departure time observations, predict its arrival and departure delay distribution at any downstream station.

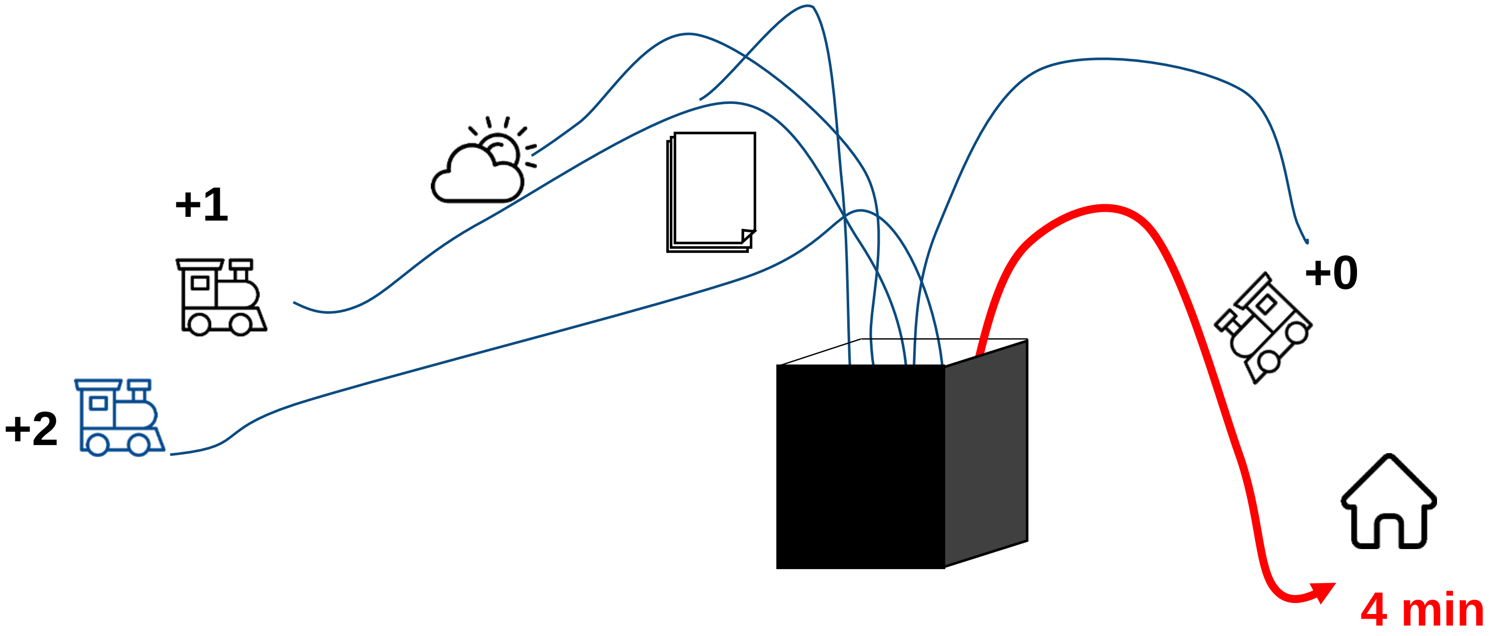


[Schaafsma, 2009]

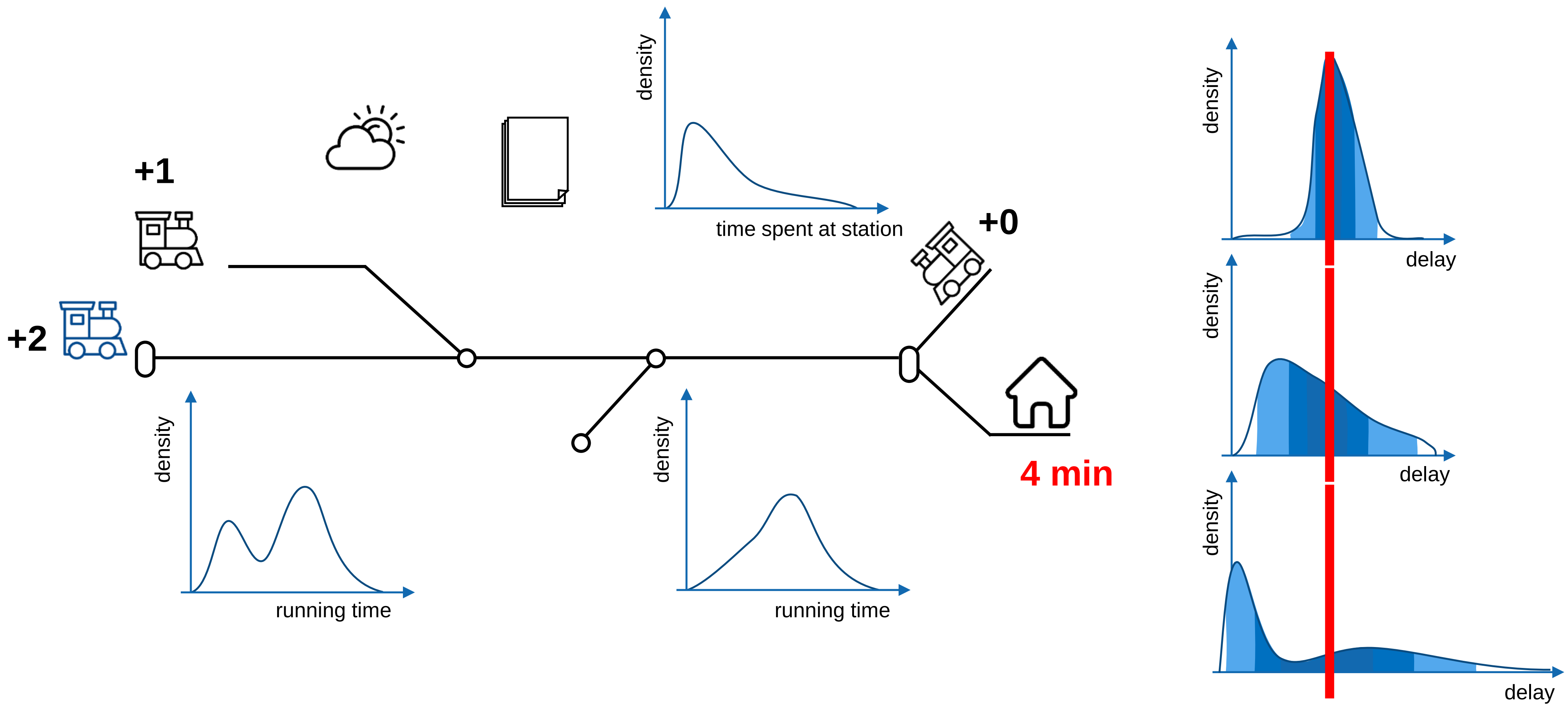
Constraints, dynamics of railway operations and a lot of influences



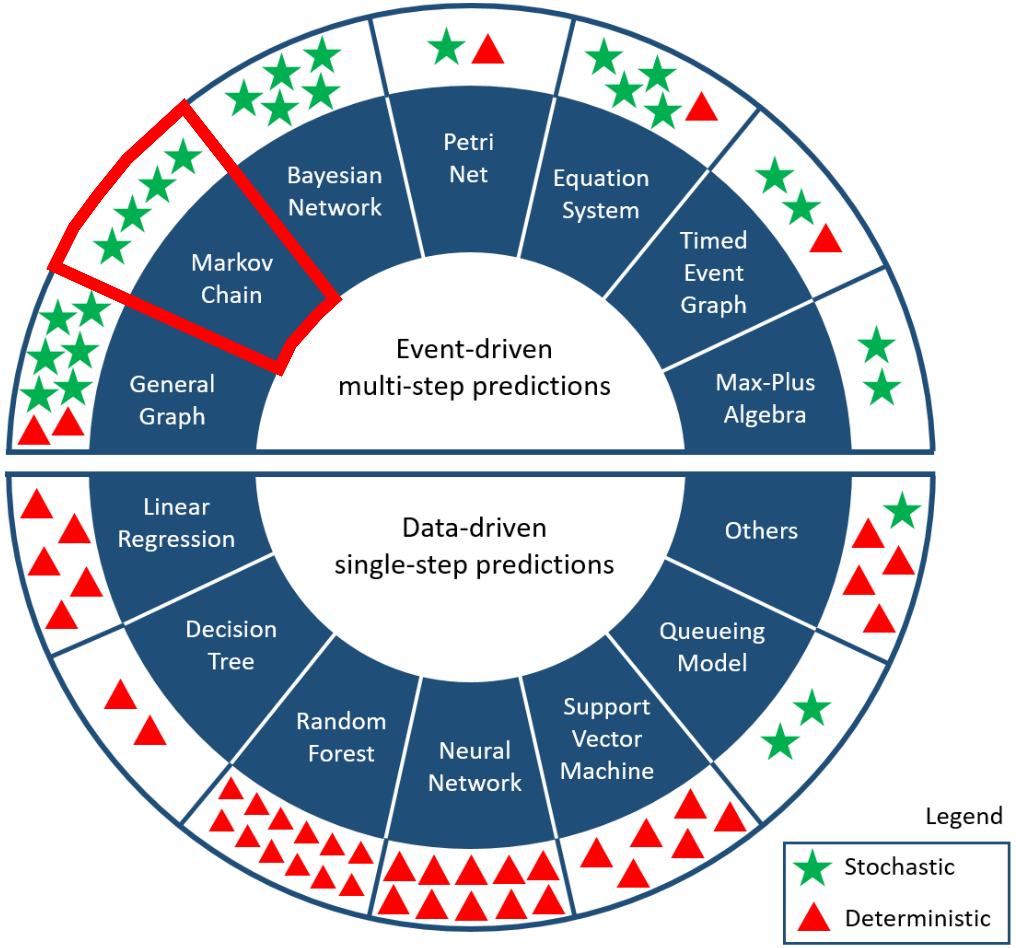
Data-driven prediction approaches exploit patterns in the data



Event-driven approaches can model system constraints, and describe the uncertainty within railway operation dynamics



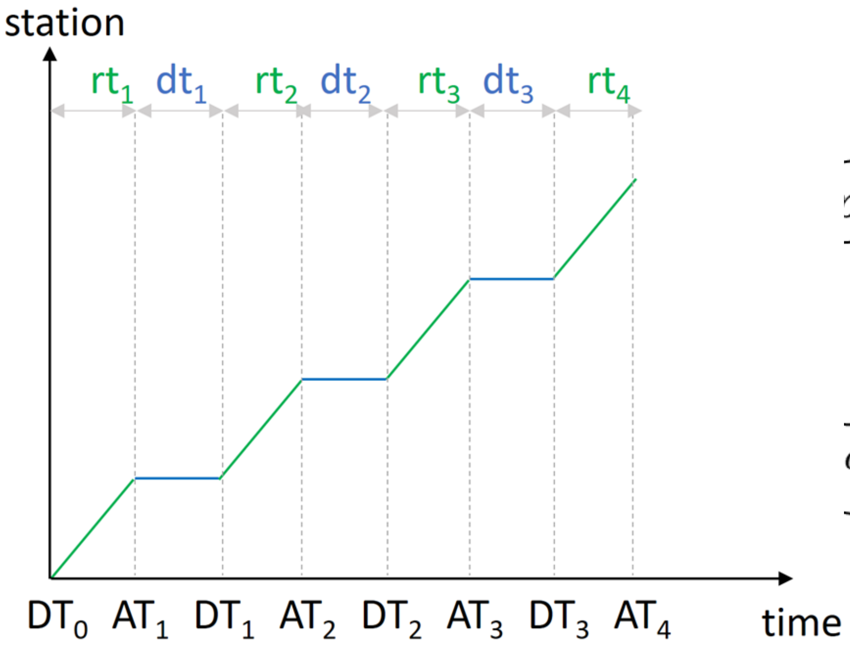
Train Delay Prediction

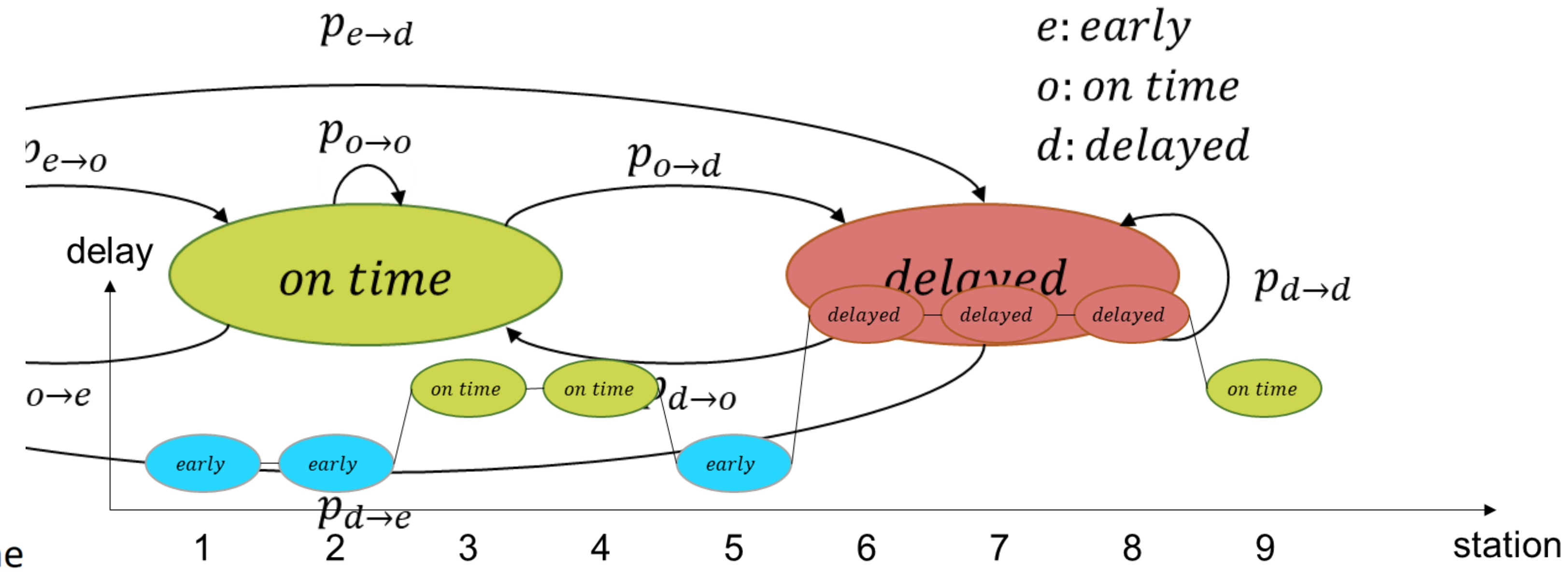


Spanninger, T., Trivella, A., Büchel, B., & Corman, F. (2022). A review of train delay prediction approaches. *Journal of Rail Transport Planning & Management*, *22*, 100312.

- Vast literature on railway delay prediction models
- When to use which model?
- Markov Chains are …
  - event-driven
  - stochastic
  - simple
  - interpretable

Markov Chain Model





$$AT_i = DT_0 + \sum_{k=1}^{i} rt_k + \sum_{k=1}^{i-1} dt_k$$

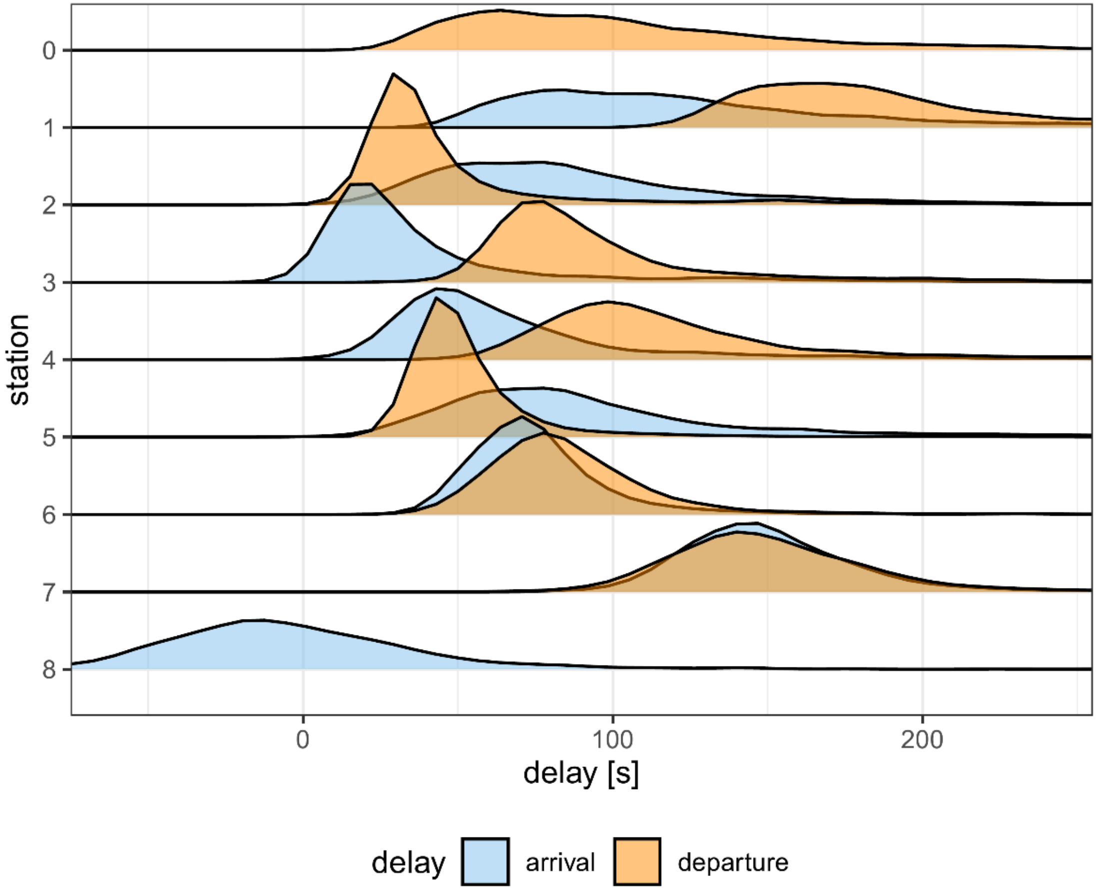
Markov Property

$$P(x_i|x_1, x_2, \dots, x_{i-1}) = P(x_i|x_{i-1})$$

State transition

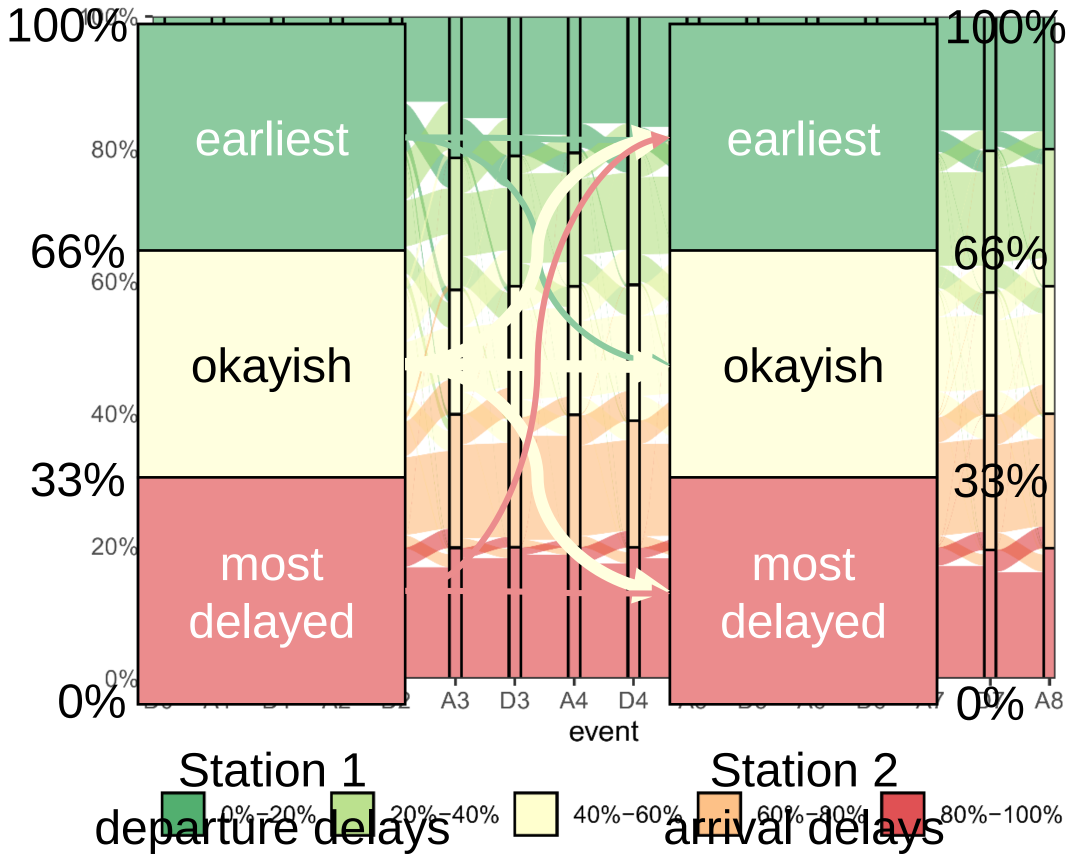
$$x_{i+1} = T \cdot x_i$$

Case Study
Buchs SG – St. Margrethen SG

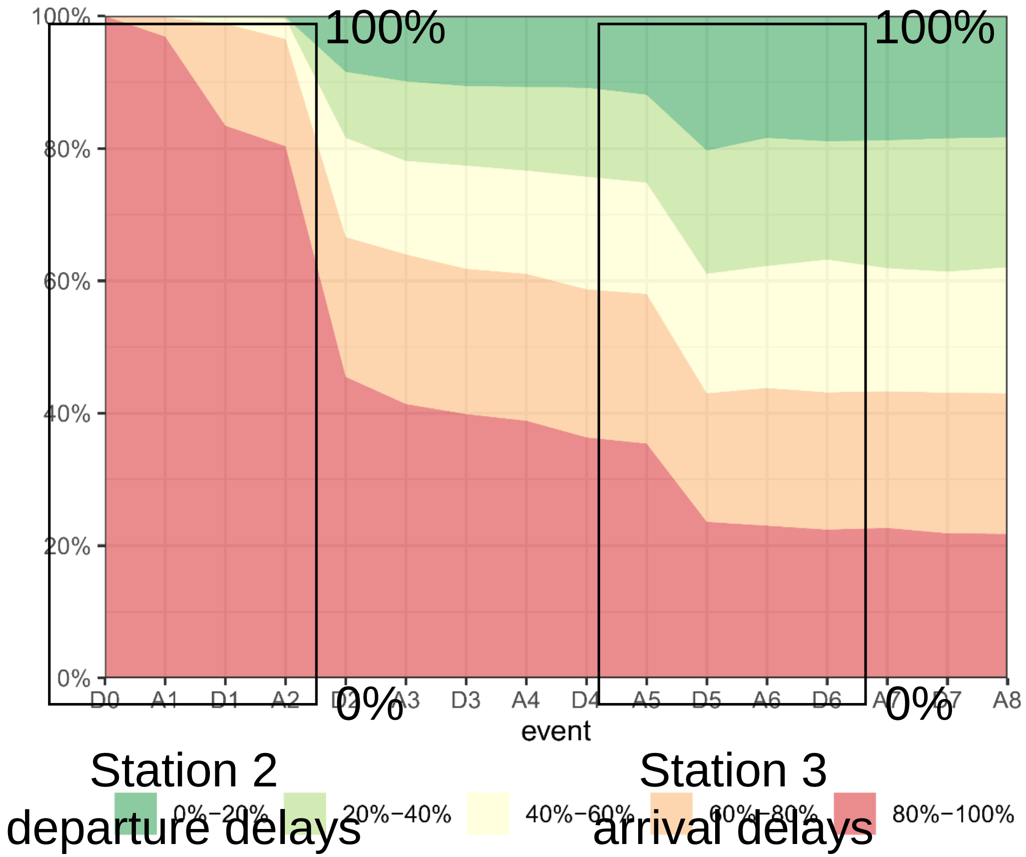


Application of Markov Chain Models

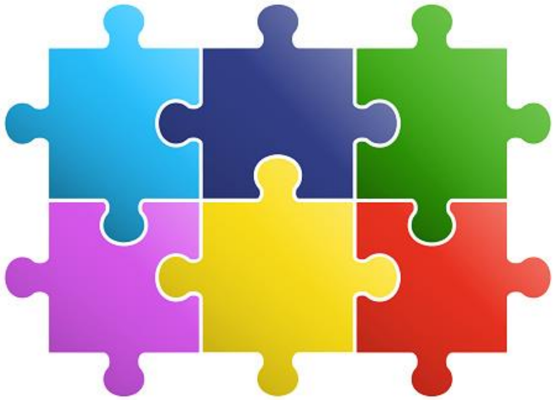
States and Transitions



Probabilistic Prediction



What is the best Markov Chain Setting



1. Parameters to choose
2. Evaluation of model settings

Dependency structure

- Events → Events
- Processes → Processes
- Order of Markov Chain

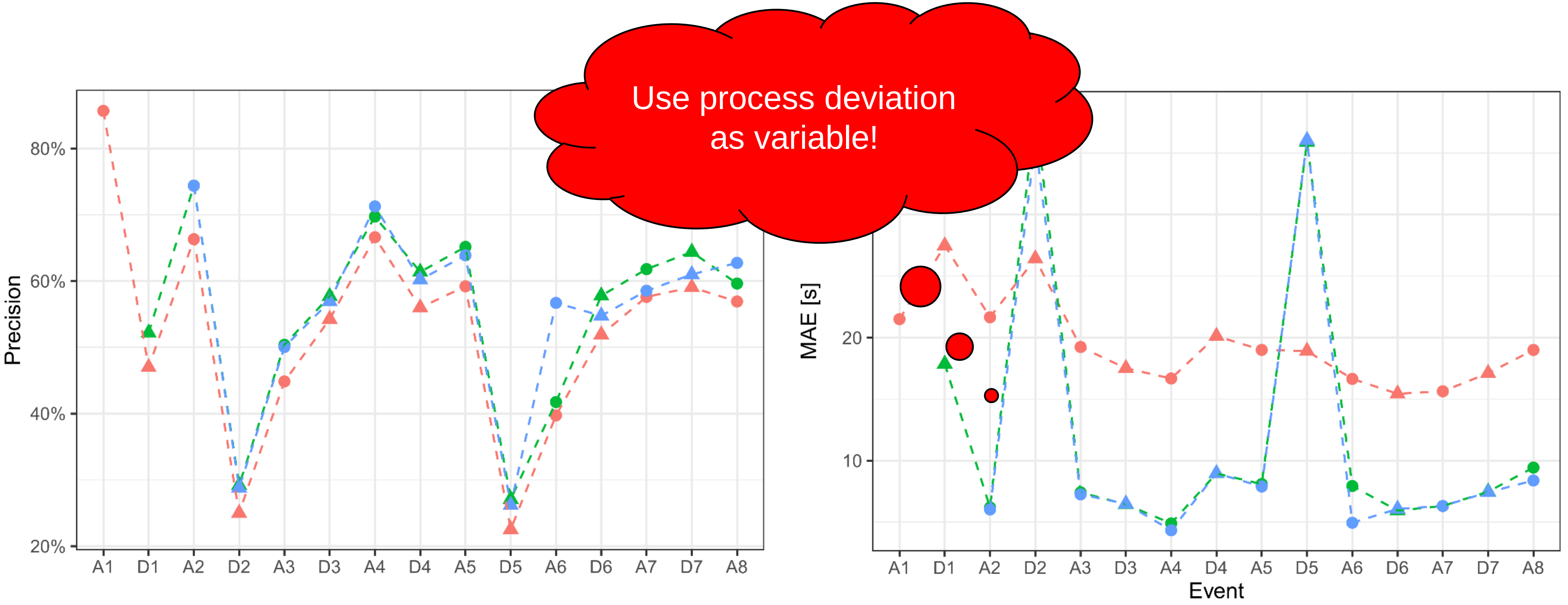
Delay Bins

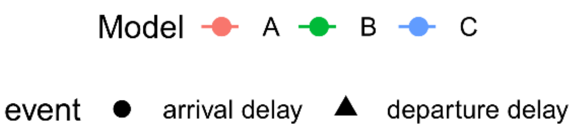
- Number of bins
- Static (domain) binning
- Adaptive binning

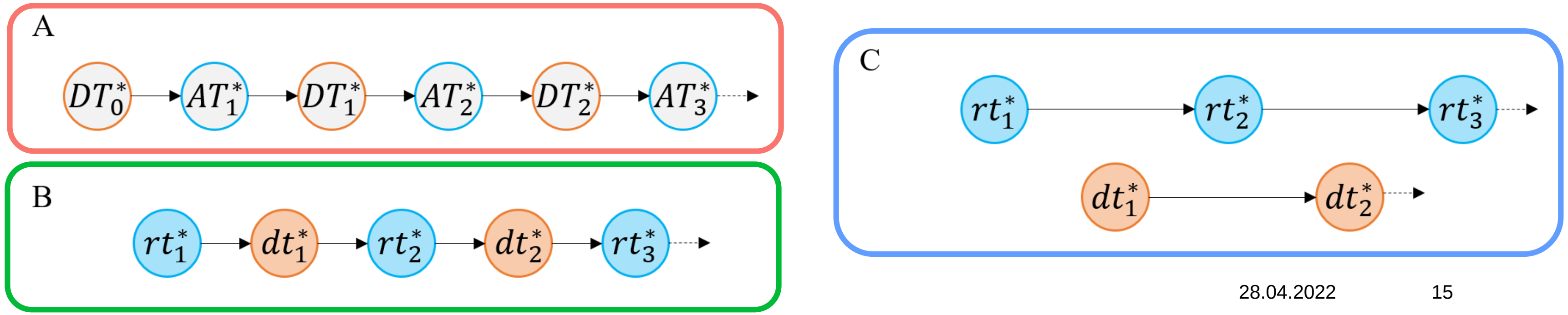
Aggregation

- Spatial
- Temporal
- Train/Line heterogeneity

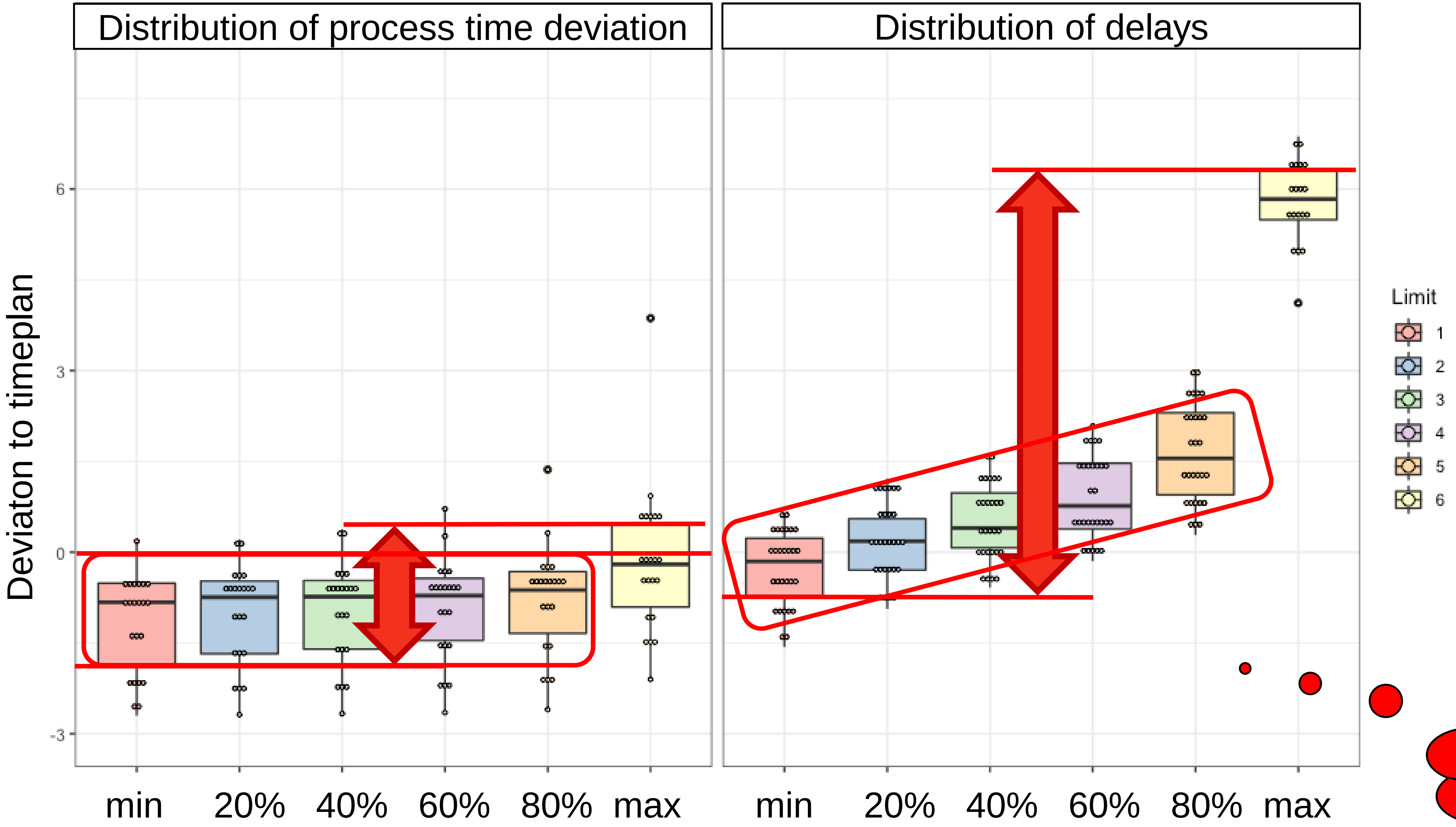
Dependency structure







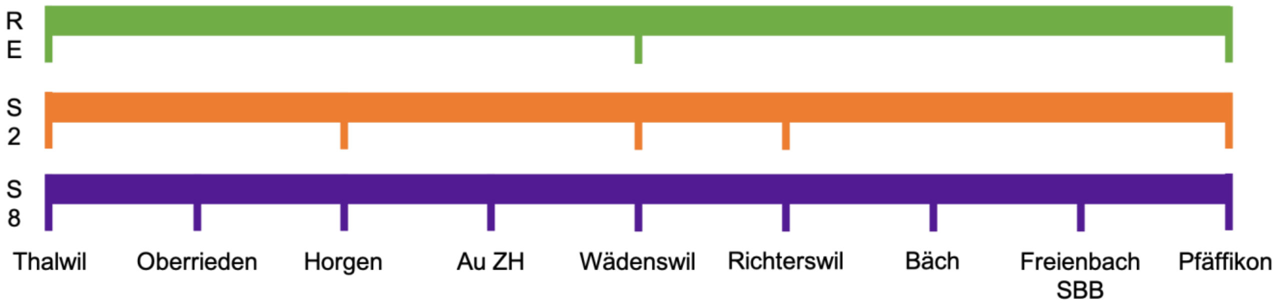
Events and Processes: Variability

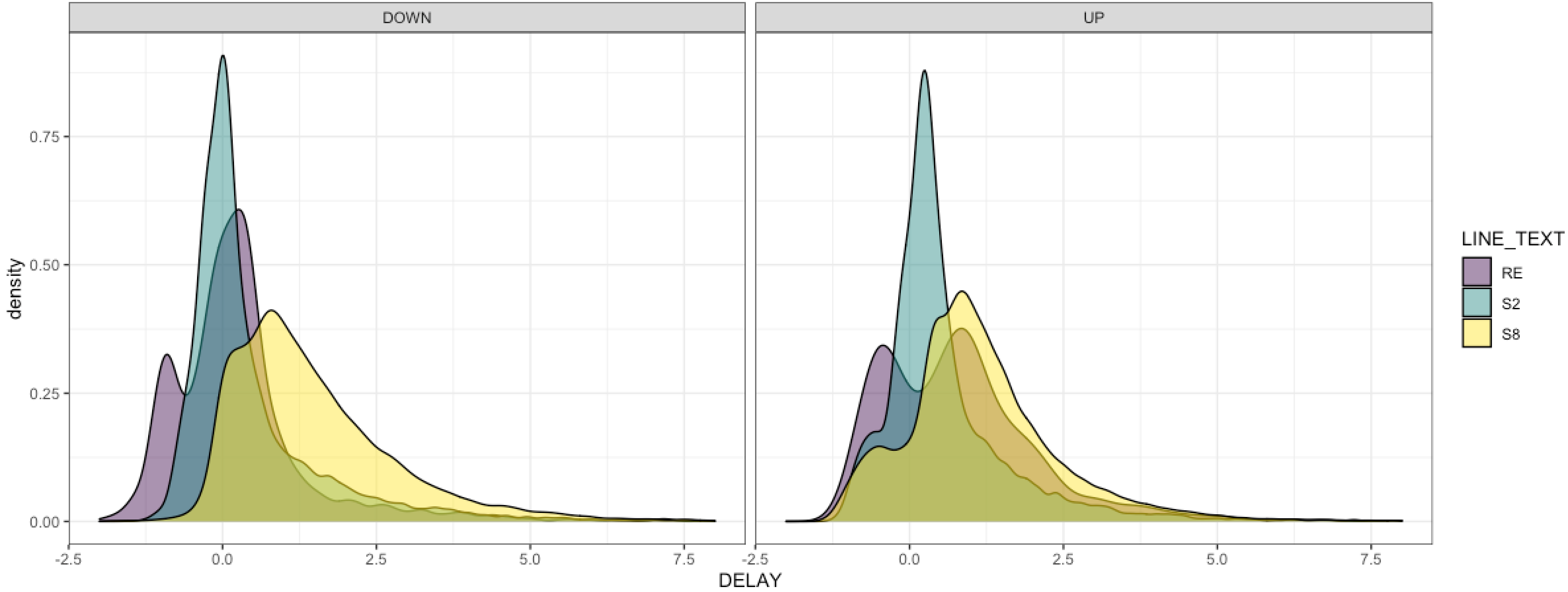


1. Running processes are shorter than planned
2. 80% of runs shorter than planned, 80% quantile of absolute delays already +1 min
3. Smaller variability in running time deviation than absolute delays

Small margins for delay absorption

Data aggregation/specification





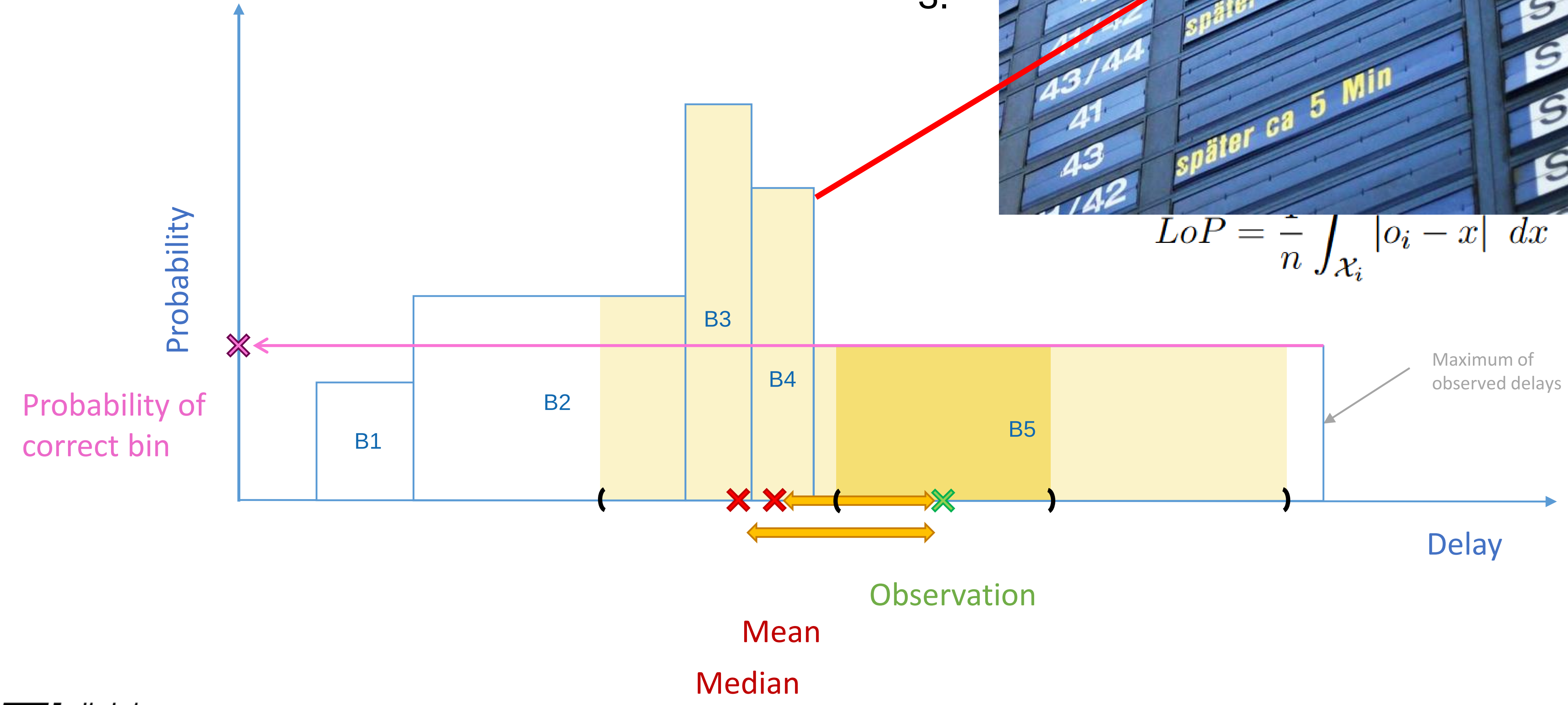
Evaluation of the prediction

1.

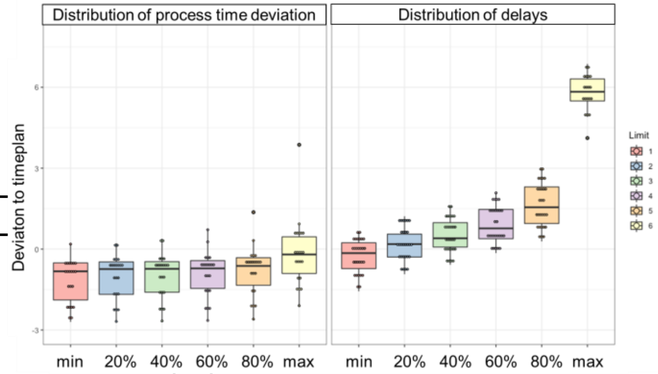
2.

3.

$$LoP = \frac{1}{n}\int_{\mathcal{X}_i} |o_i - x| \; dx$$



Number of Bins



Variable: Delay

Variable: Process time deviation

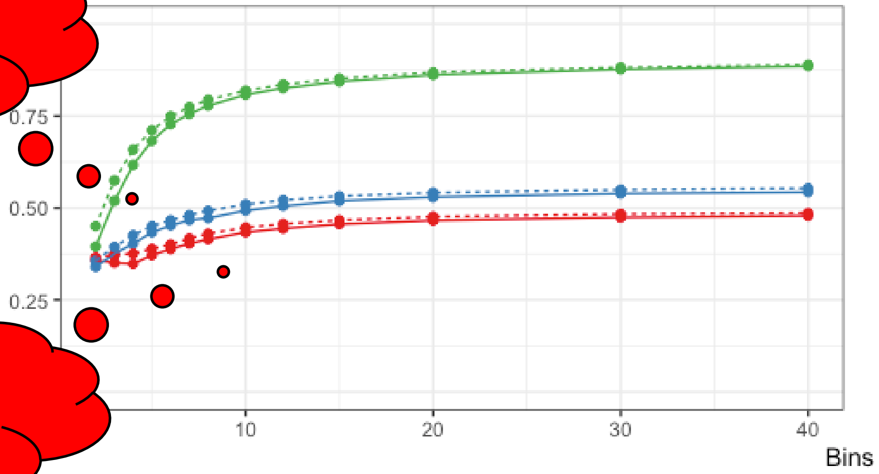
MAE (mean)

LoP x_i = 1 min

Spatial specification more important than temporal

Higher likeliness with more bins… level of saturation

Higher accuracy for models on process time deviation

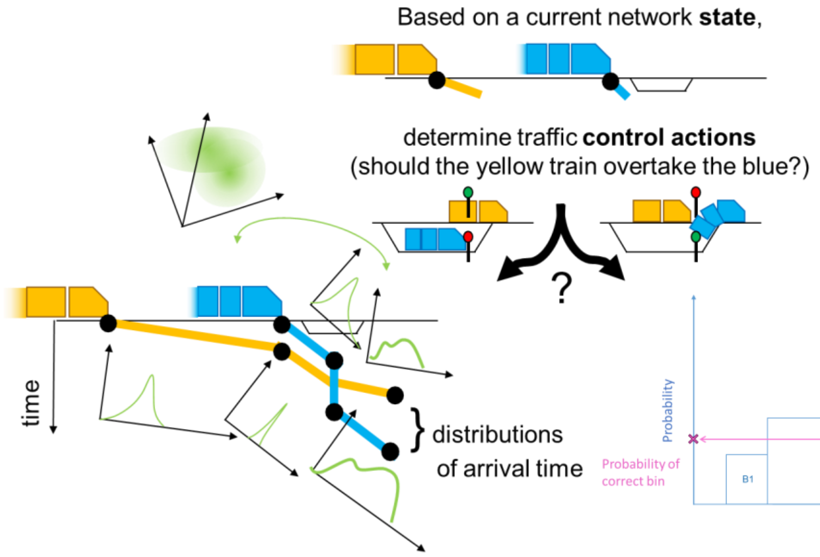


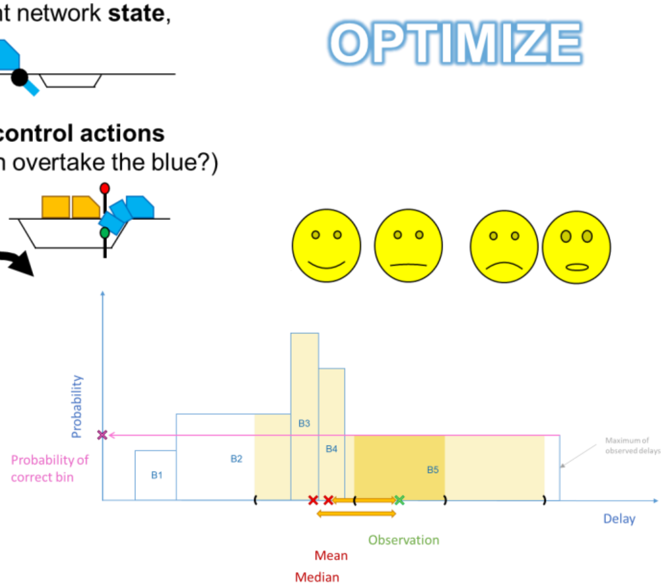
Spatial aggregation glob line locline Temporal aggregation all 1h

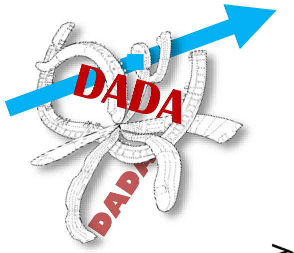
Conclusion
Markov Chain Models for Train Delay Prediction

1. Intuitive approach to describe/predict train delay evolution
2. Use process time deviations instead of absolute amounts of delays
3. Reduce uncertainty by specification of transition probabilities
    1. Spatial specification (Location heterogeneity)
    2. Line specification (heterogeneity in schedules, priorities)
    3. Temporal heterogeneity (peak / non-peak hours)
4. More bins increase the prediction performance until a point of saturation

Stochastic Optimization







Maximizing the expected value of some performance function, over all possible outcomes

Over a time horizon of possible decisions

Depending on control actions depending on the state S_t and the policy chosen

Depending on the state S_t

The cost

Based on the new information W_{t+1} available

$$\max_{\pi} E^{\pi}\left\{\sum_{t=0}^{T} C_t\left(S_t, X_t^{\pi}(S_t), W_{t+1}\right) \middle| S_0\right\}$$

Find a policy π= sequence of control actions

Based on a starting state S_0

$$S_{t+1} = S^M\left(S_t, x_t, W_{t+1}(\omega)\right)$$

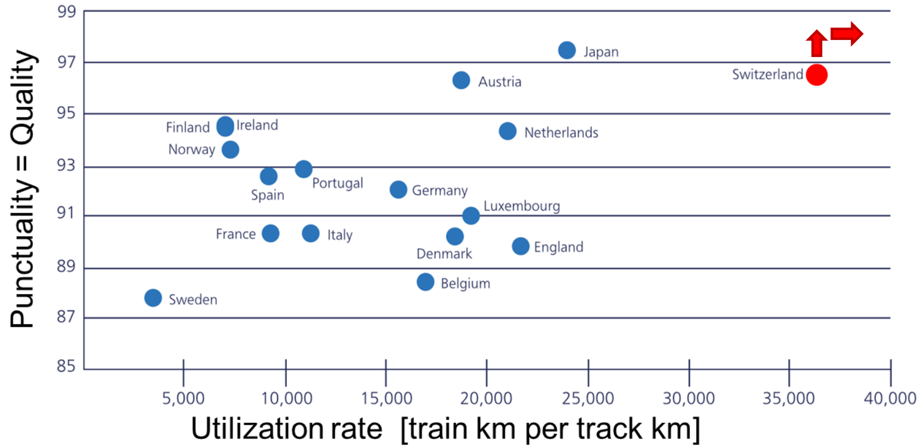
State evolves over time based on

a set of states, function of

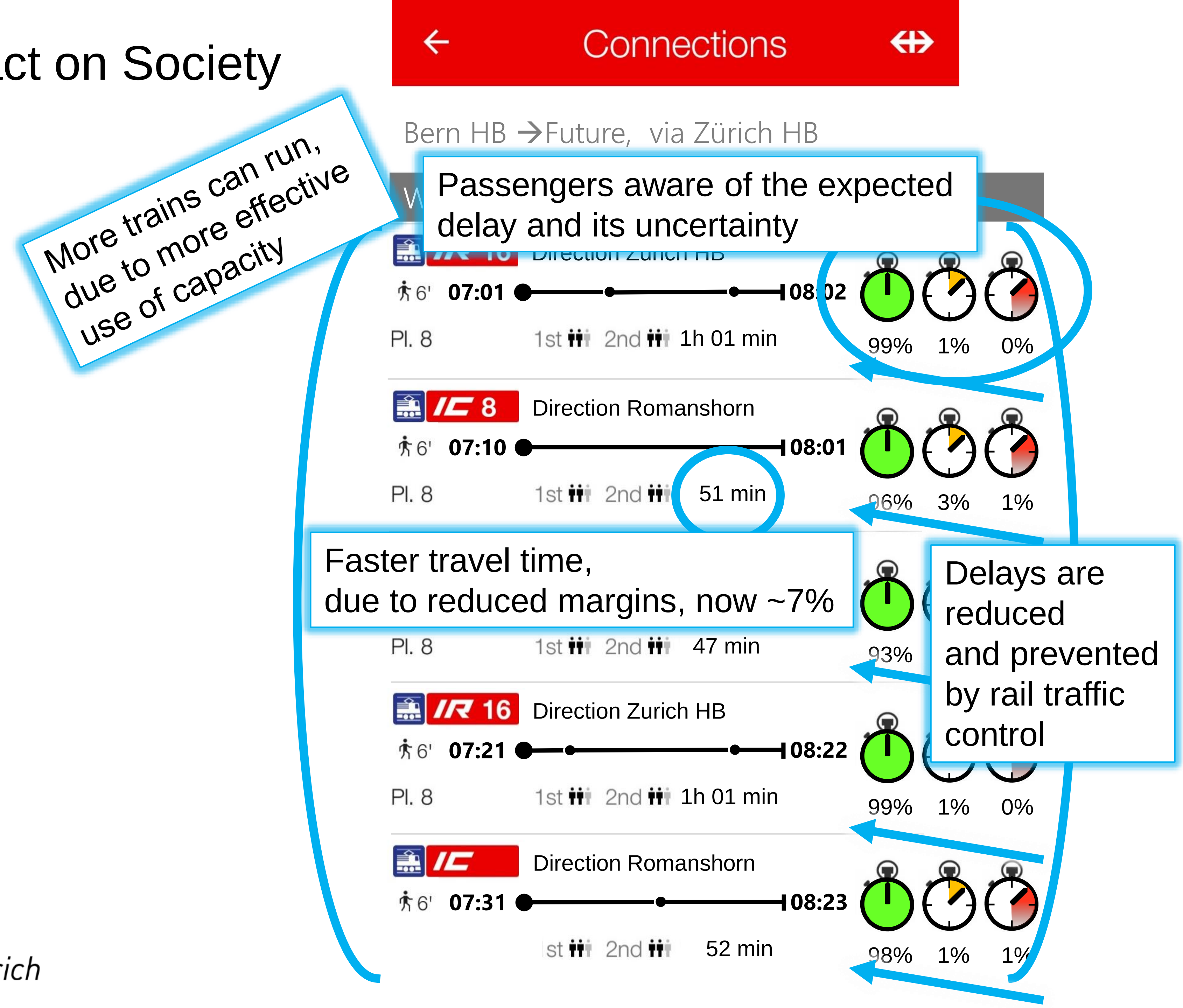
The previous state

The control actions chosen

And some information on a stochastic process ω



Impact on Society



REFERENCES

Büchel, B., Spanninger, T., & Corman, F. (2021, June). Modeling Evolutionary Dynamics of Railway Delays with Markov Chains. In *2021 7th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)* (pp. 1-6). IEEE.

Schaafsma, A. A. M., & Weeda, V. A. (2009). Operation-driven scheduling approach for fast, frequent and reliable railway services. In *Proceedings of the 3rd International Seminar on Railway Operations Modelling and Analysis (IAROR), Zurich, Switzerland*.

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ETH zürich

Thank you!

Thomas Spanninger
tspanninger@ethz.ch