Faculty of Transportation and Traffic Sciences "Friedrich List"

Institute for Traffic Telematics • Chair of Traffic Control and Process Automation

The Impact of Request Stops on Railway Operations

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Agenda

1. Introduction
2. Present Request Stop Usage
3. Modeling Train Approaches at Request Stops
4. Optimizing Energy Consumption and Delays
5. Case Study
6. Conclusions

1. Introduction

- Wide variety of measures to reduce energy costs
- Request stop – train only stops on demand
  - → Influence on energy consumption unknown
  - → Significant difference for energy optimization

- Time slack with compulsory stops only:

$$t_r = \sum_{i=1}^{n} t_{F,i}$$

Scheduled time slack

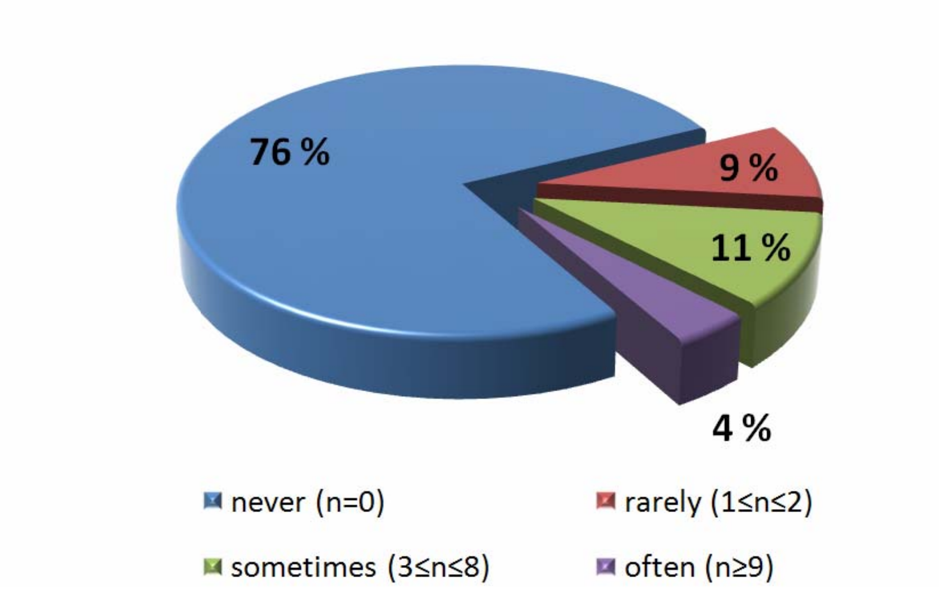
- Time slack with request stops:

$$t_r = \sum_{i=1}^{n} t_{F,i} + \sum_{j=1}^{m} t_{g,j}$$

Additional time gain

2. Present Request Stop Usage

- Strongly varying usage of request stops on German railway lines



Appearance of request stops on local German railway lines (01/2008)

2. Present Request Stop Usage

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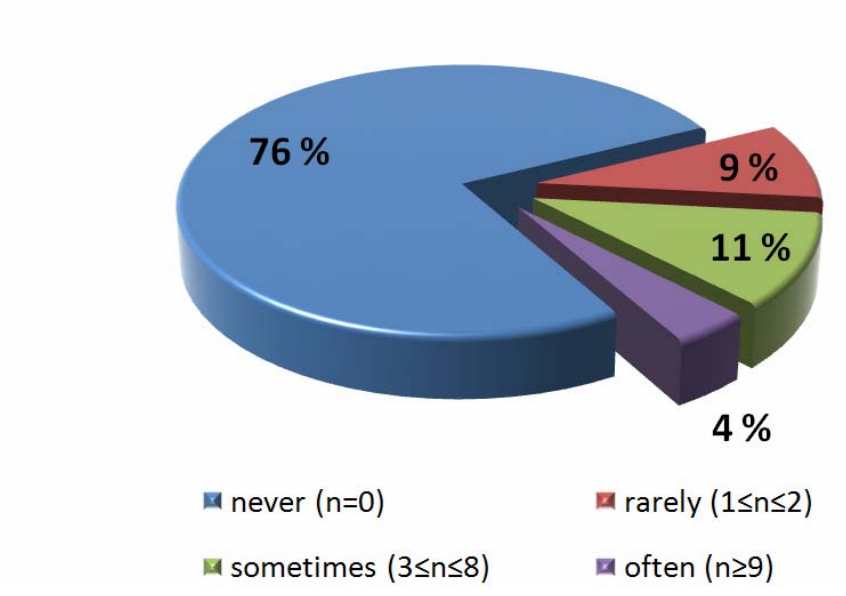


Appearance of request stops on local German railway lines (01/2008)

Pro

+ Increase mean transport speed
+ More recovery time as timetable buffer
+ More recovery time for saving energy

2. Present Request Stop Usage

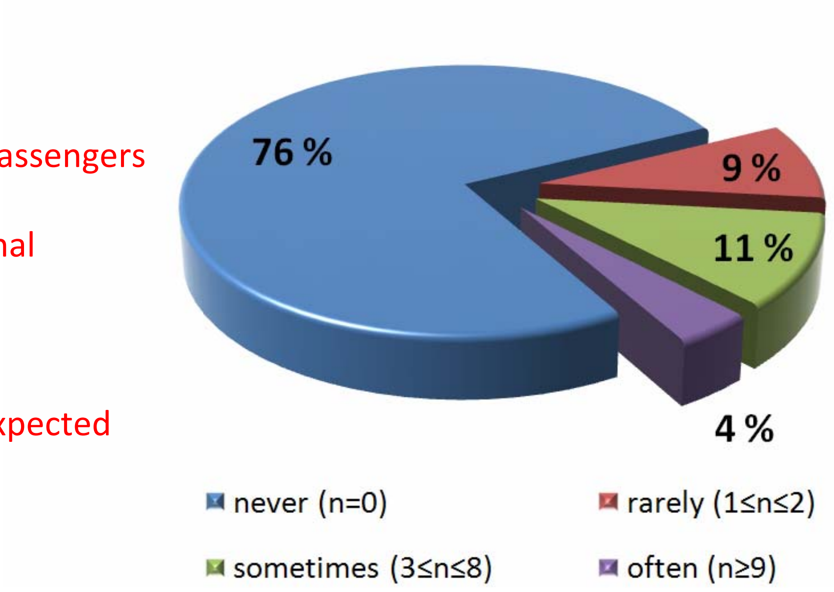
- Strongly varying usage of request stops on German railway lines

Contra

- Overlooking of waiting passengers

- Inefficient use of additional running time slack (early arrivals)

- Increasing delays by unexpected stop requests



Appearance of request stops on local German railway lines (01/2008)

Pro

+ Increase mean transport speed

+ More recovery time as timetable buffer

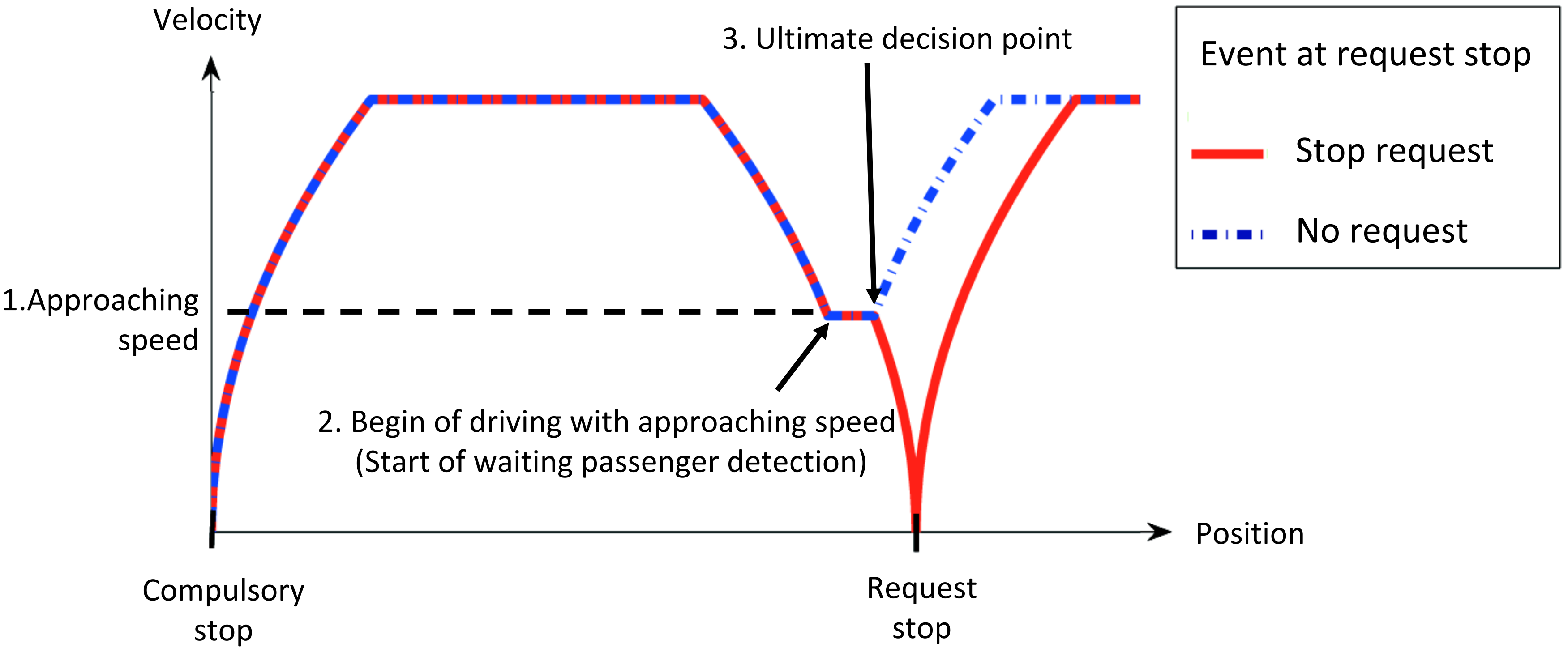
+ More recovery time for saving energy

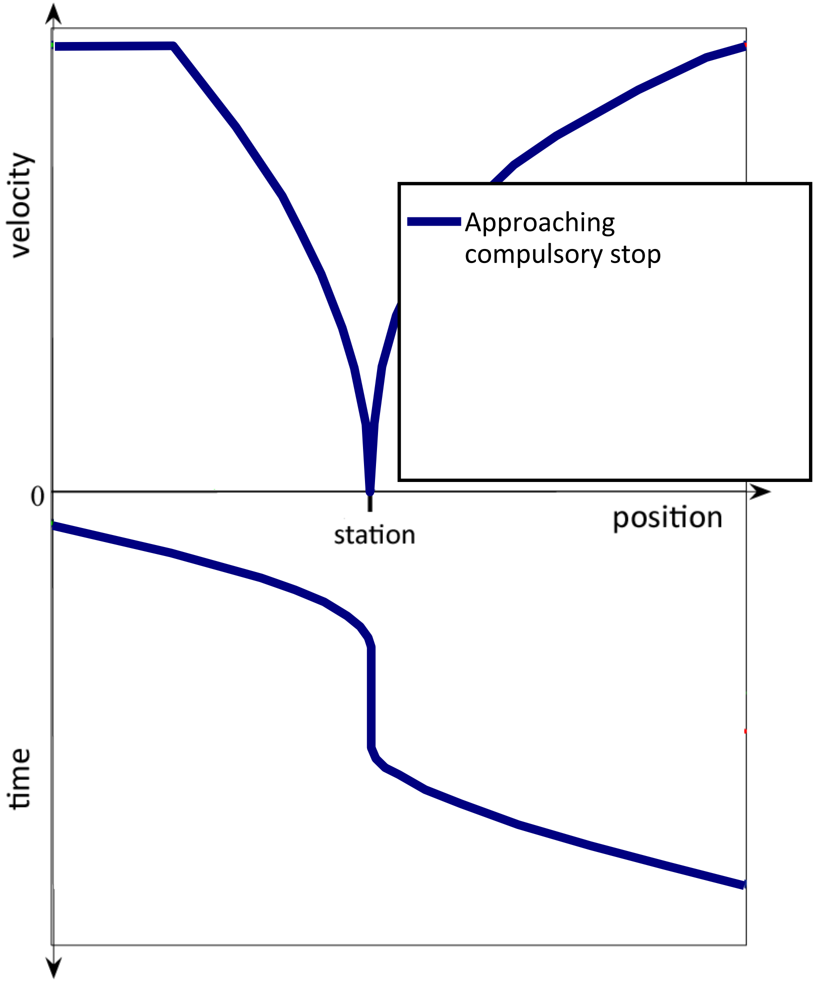
Task for Modeling and Optimization:

Find the optimal driving strategy considering the features of request stops !

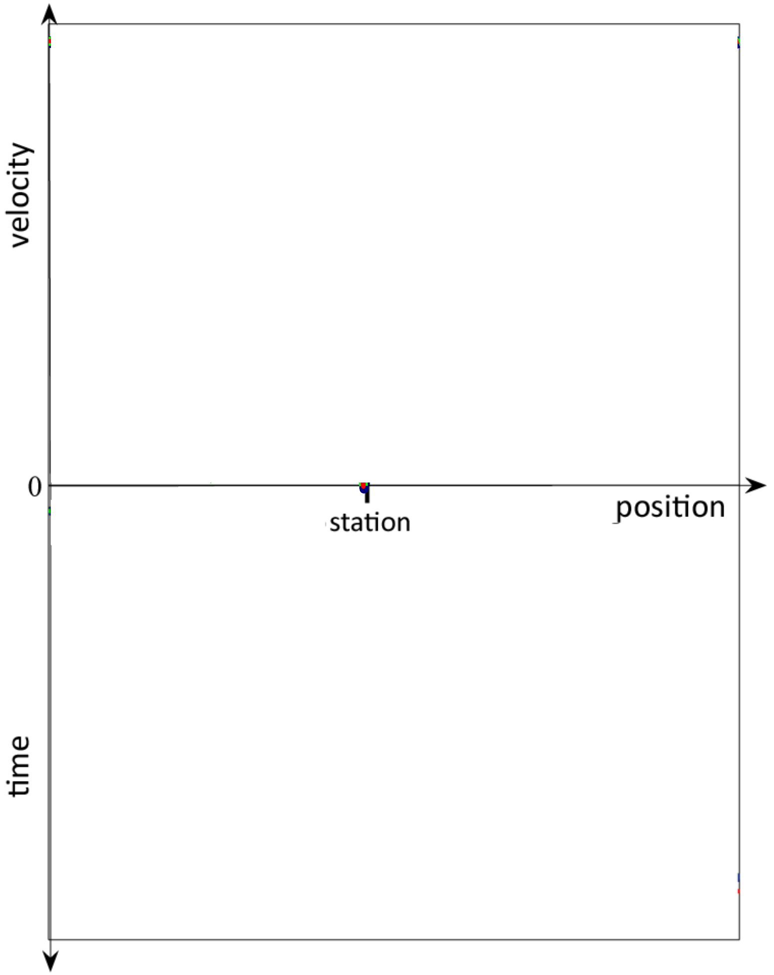
- **Energy-efficient** and **timetable consistent** distribution of time slack
- Appropriate model of train approaches at request stops

3. Modeling Train Approaches at Request Stops

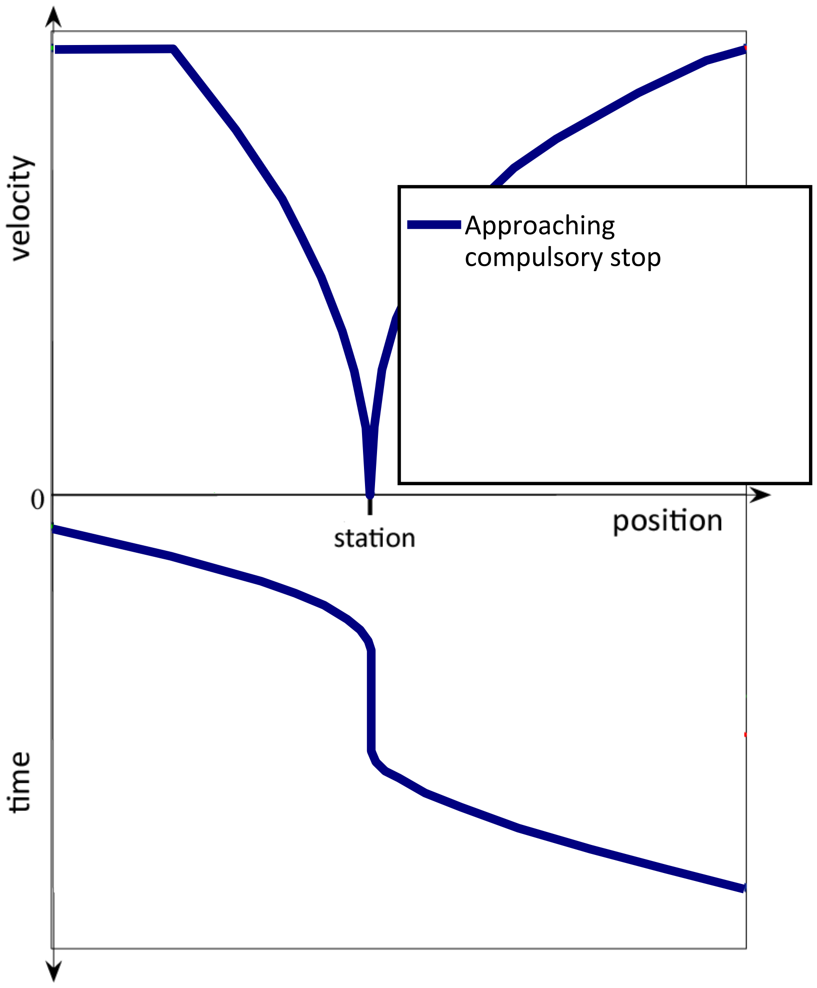




No stop request



Stop request



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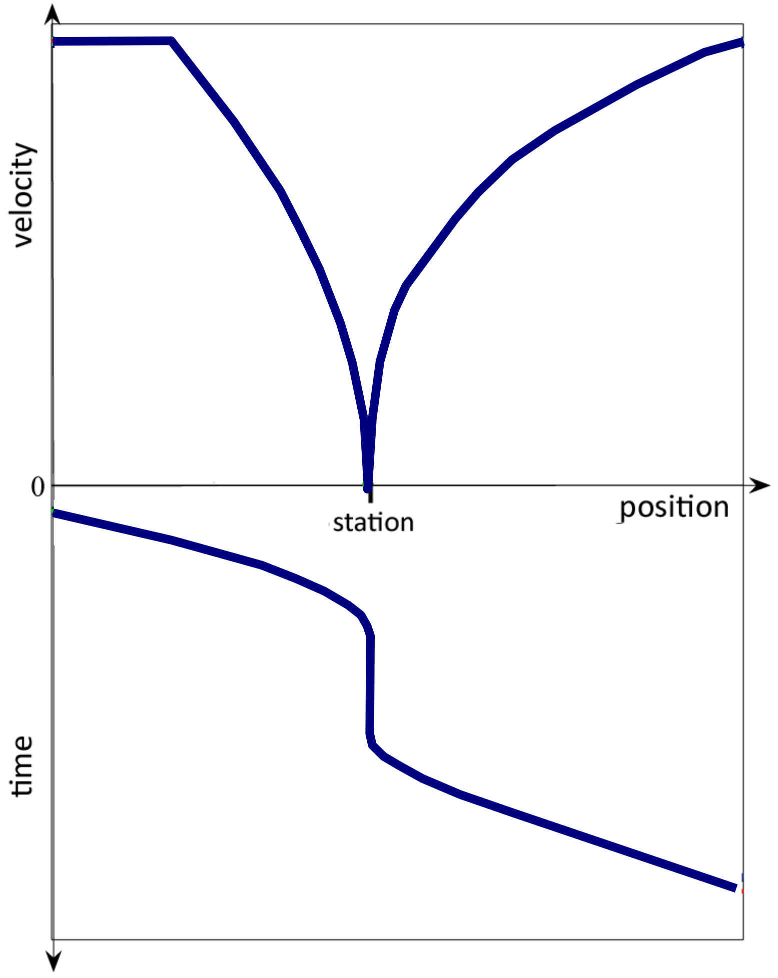
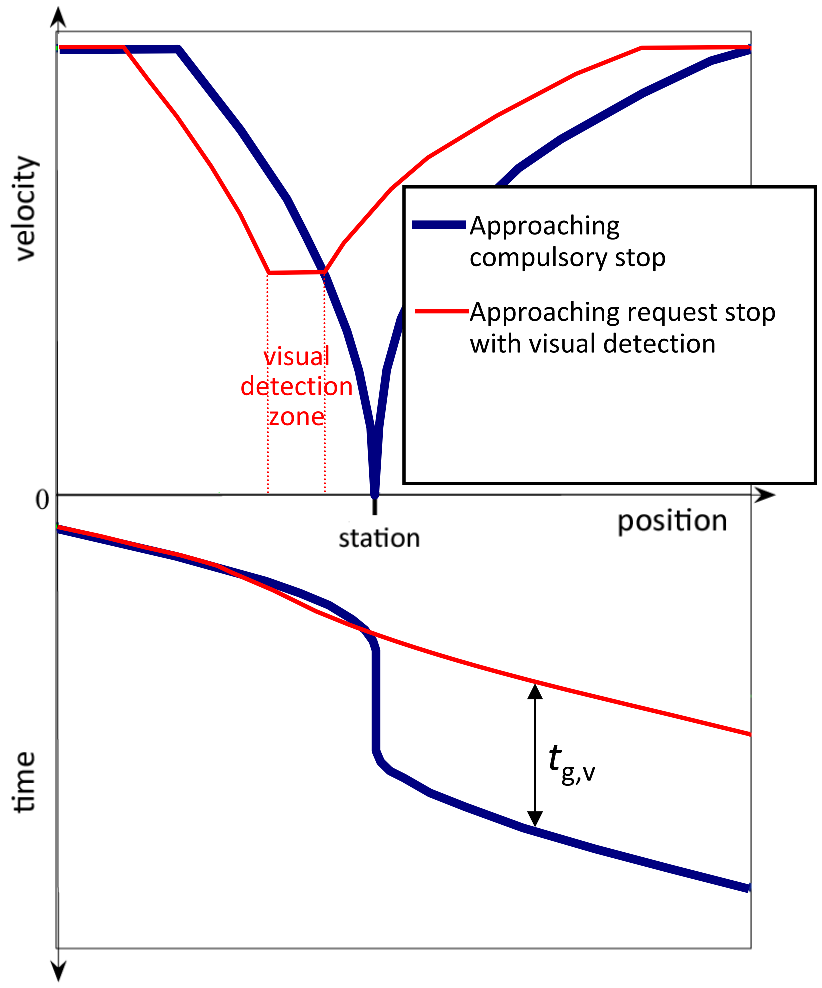


Stop request



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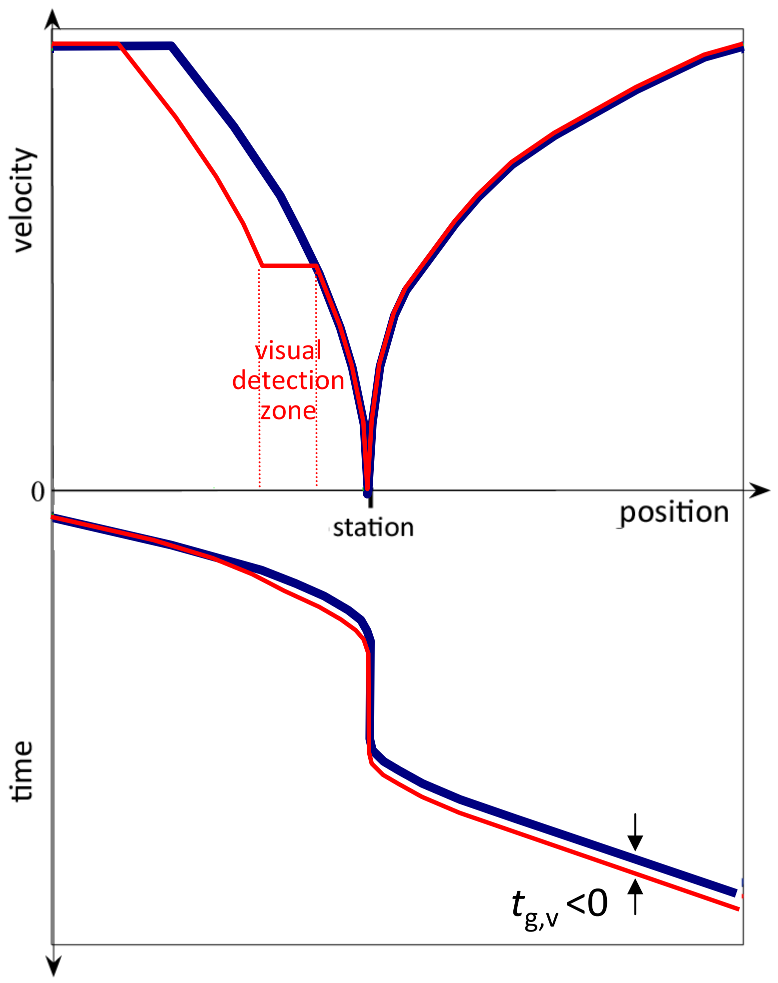
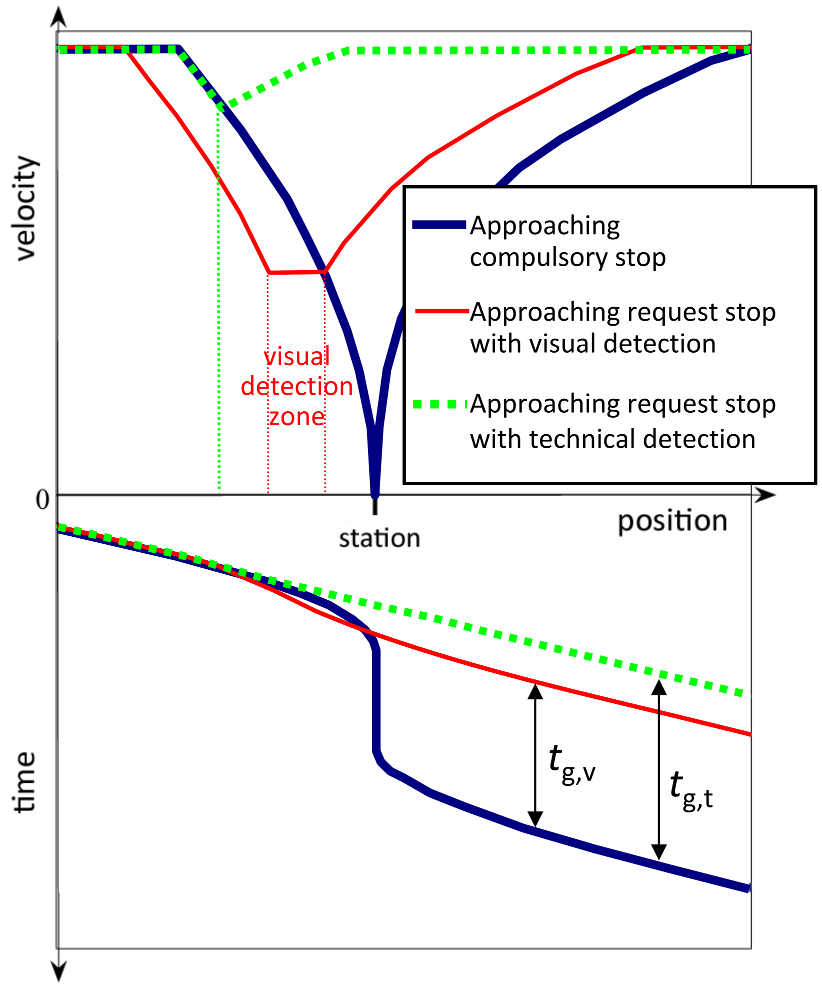


Stop request



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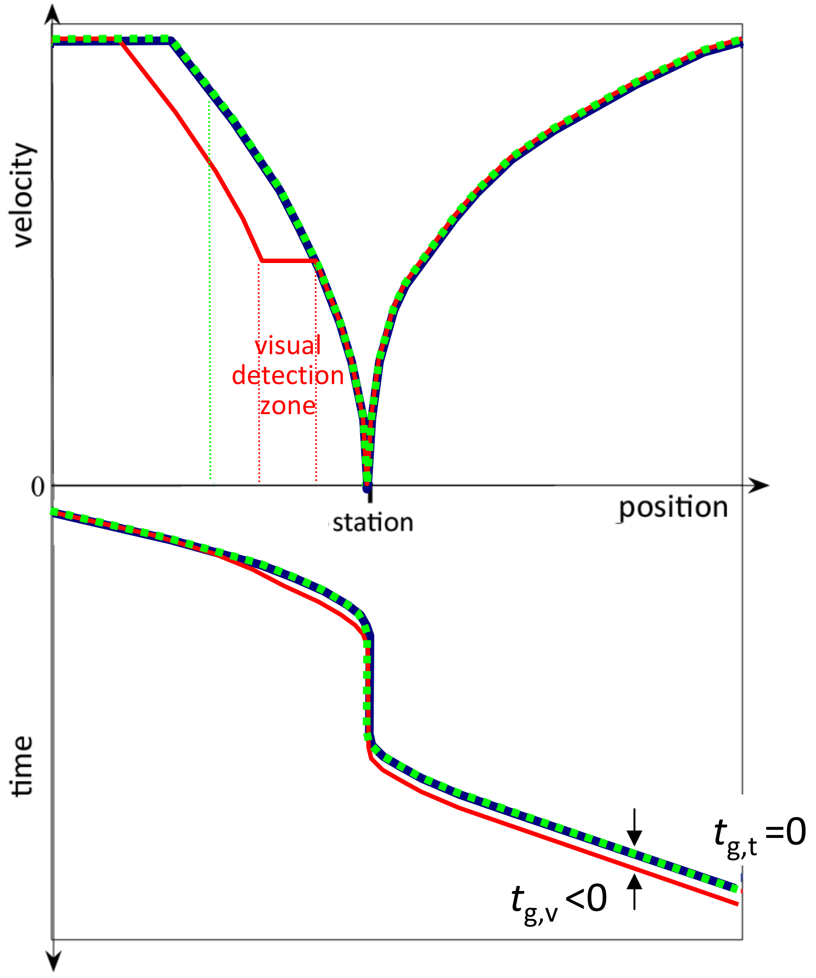


Stop request

4. Optimizing Energy Consumption and Delays

4.1 Prediction of running time reserves

$$t_{\mathrm{r}} = t_{\mathrm{s}} - \sum_{i=1}^{I} t_{\mathrm{h},i} - \sum_{j=1}^{J} t_{\mathrm{min},j}$$

Running time reserve

Scheduled time

Dwell time

Minimum running time

4. Optimizing Energy Consumption and Delays

4.1 Prediction of running time reserves

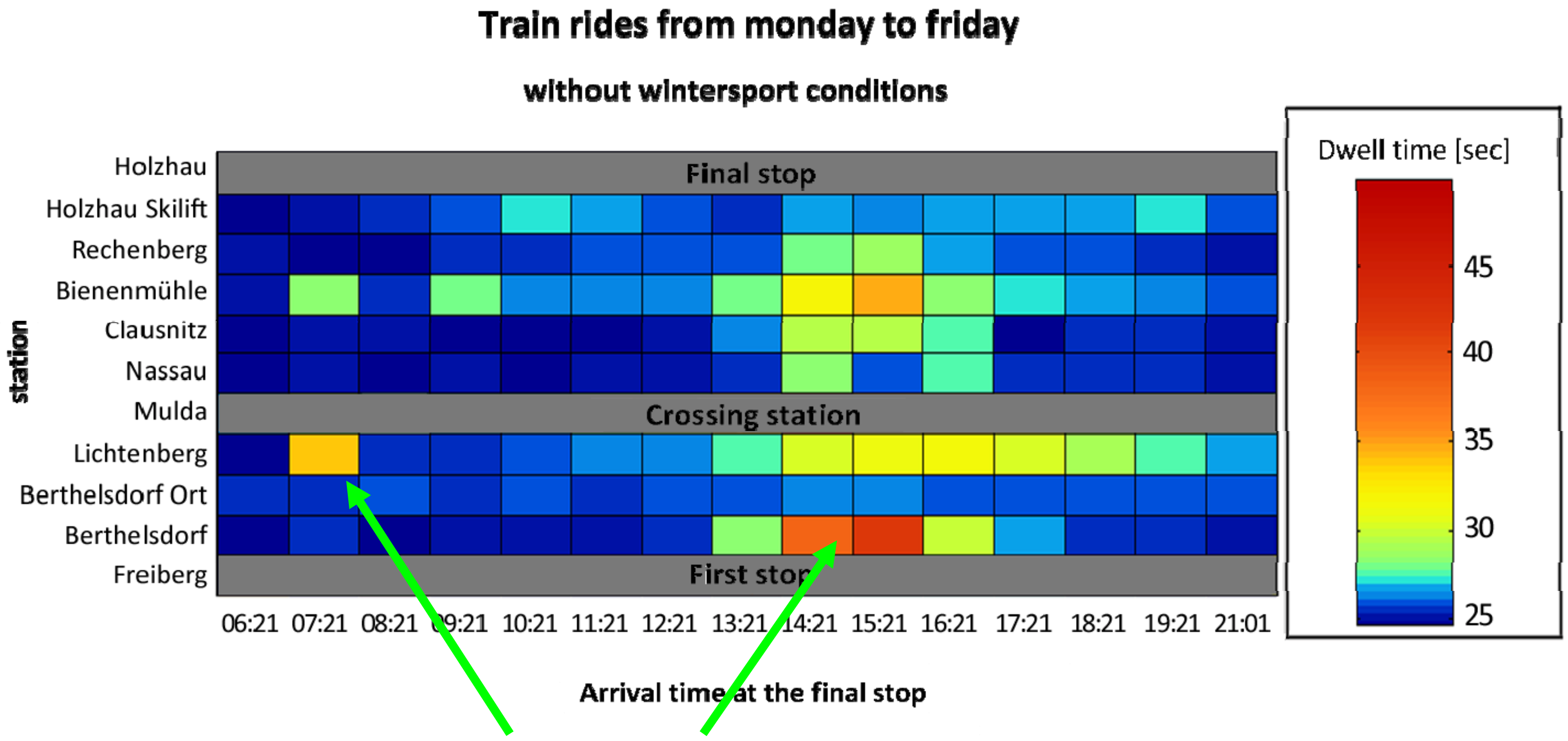
$$t_{\mathrm{r}} = t_{\mathrm{s}} - \sum_{i=1}^{I} t_{\mathrm{h},i} - \sum_{j=1}^{J} t_{\mathrm{min},j}$$

- Prediction of dwell times in categorical clusters

- Analysis of alighting and boarding passenger data

4. Optimizing Energy Consumption and Delays

4.1 Prediction of running time reserves



Identification of long dwell times ↔ small running time reserves

4. Optimizing Energy Consumption and Delays

4.2 Time Slack Distribution Algorithm

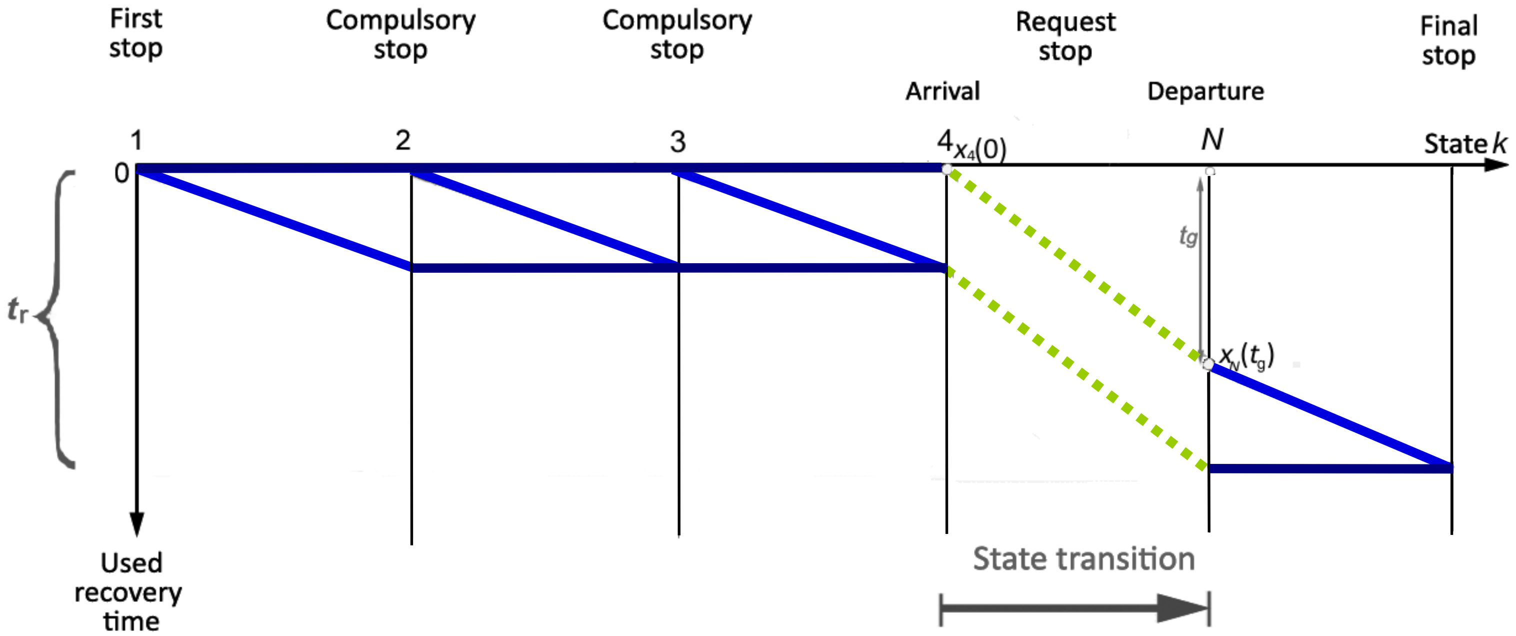
- Distribution of time slack on each section by Dynamic Programming
- Strategies of distributing time gain:

(1) re-active distribution

- Assumption: Each request stop will be served
- No distribution of time gain t_g before this assumption is rejected (passing the request stop)
- No delays because of request stops

Re-active distribution strategy

- Main assumption: train has to serve the request stop



Re-active distribution strategy

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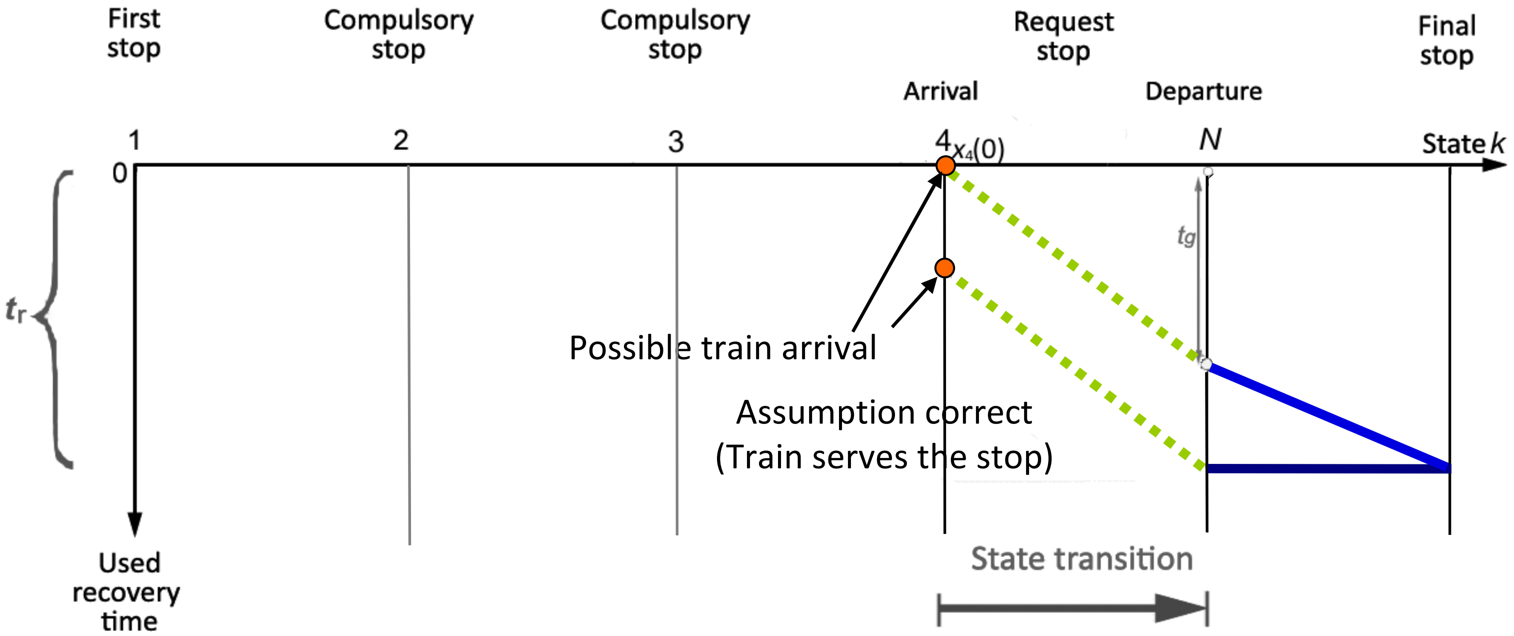
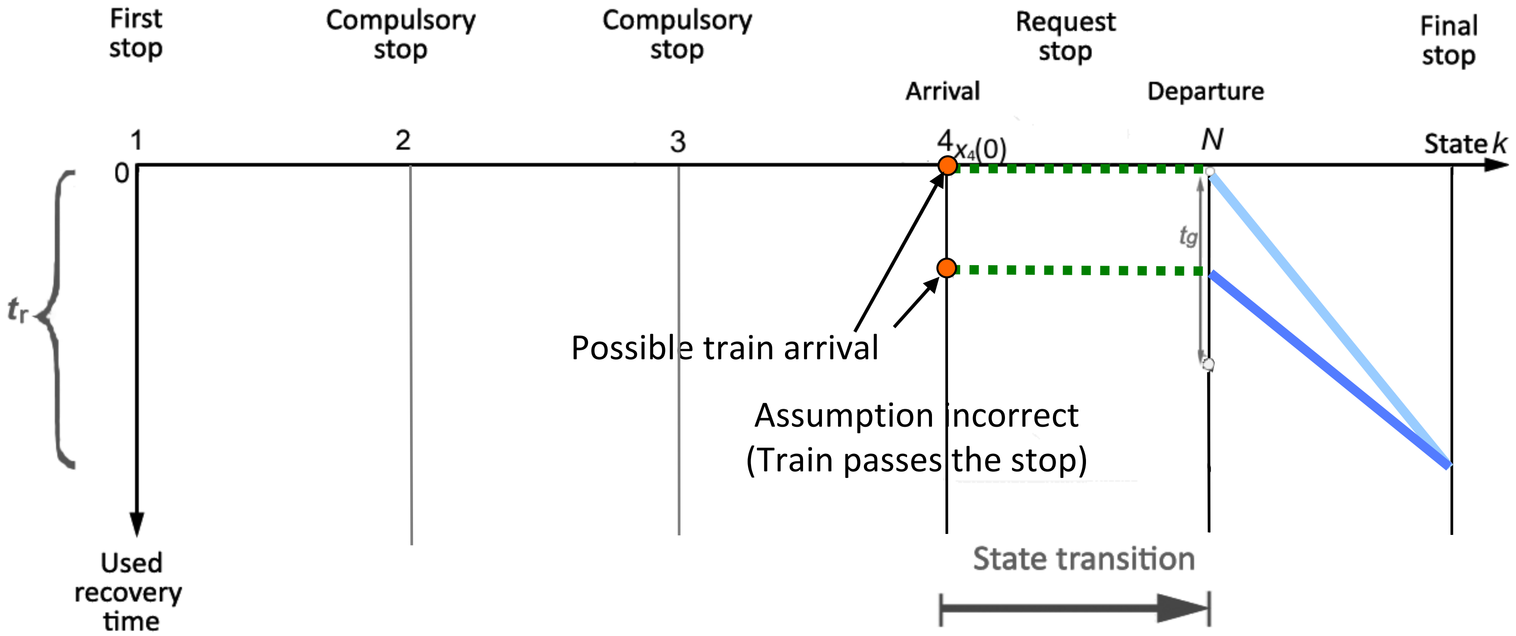


Possible train arrival

Assumption correct
(Train serves the stop)

Re-active distribution strategy

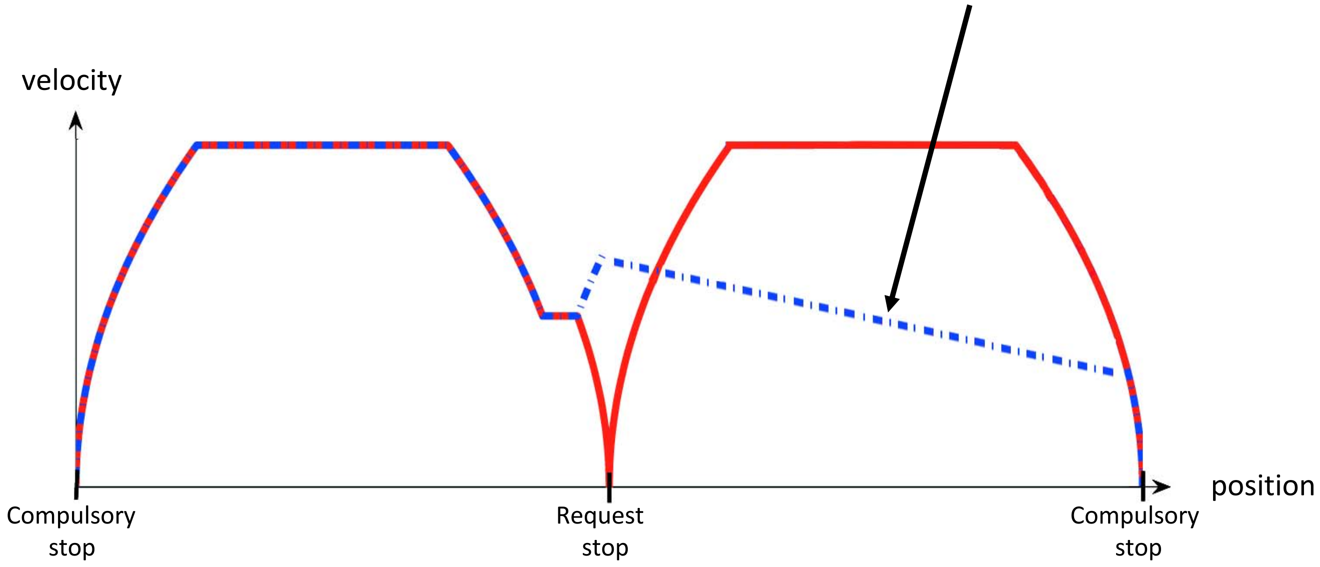
- Main assumption: train has to serve the request stop



Possible train arrival

Assumption incorrect
(Train passes the stop)

Re-active distribution strategy



High concentration of time gain t_g

4. Optimizing Energy Consumption and Delays

4.2 Time Slack Distribution Algorithm

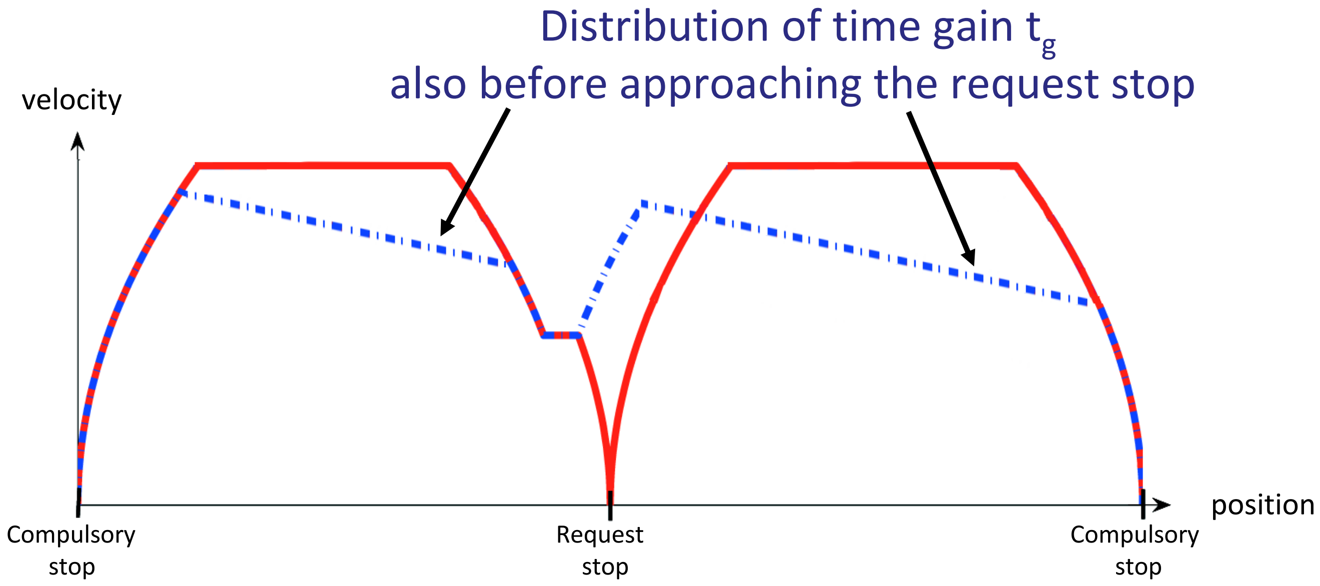
- Distribution of time slack on each section by Dynamic Programming
- Strategies of distributing time gain:

(1) **re-active distribution** (assumption: train will definitely stop)

(2) **pro-active distribution** (assumption: train will pass with a certain probability)

Pro-active distribution strategy

- Distribution of time gain on all sections
- Delays are accepted for the benefit of less energy consumption


Distribution of time gain t_g
also before approaching the request stop

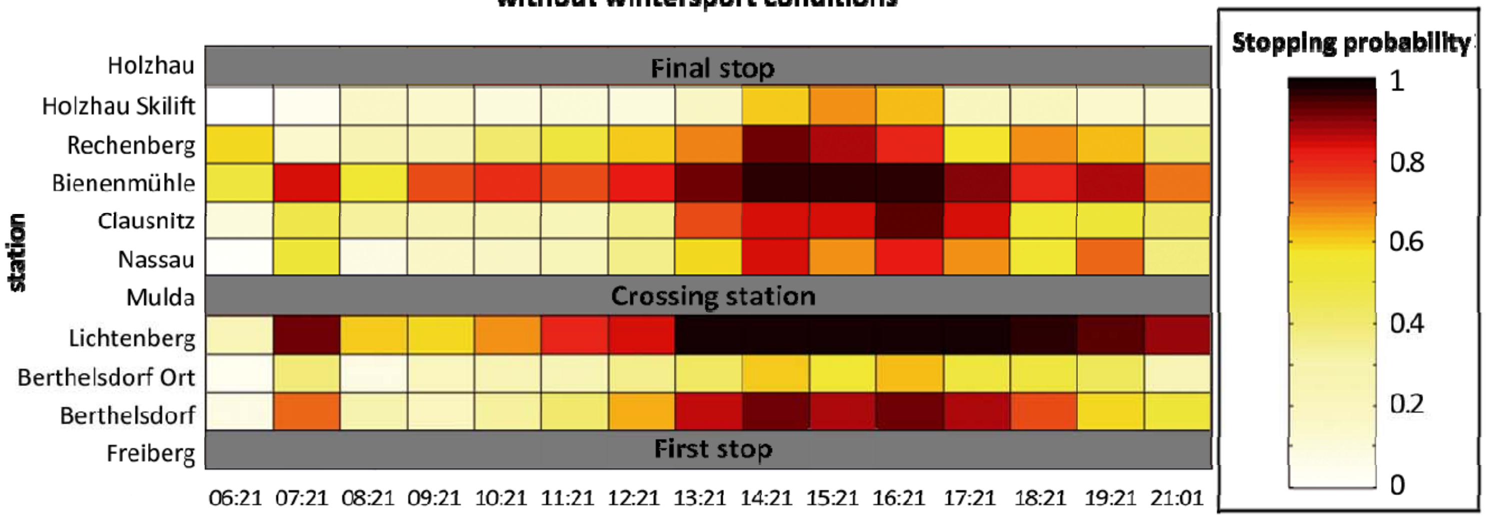
Pro-active distribution strategy

- Approach: Probabilistic state transition at request stops

→ involving stopping probability of each stop

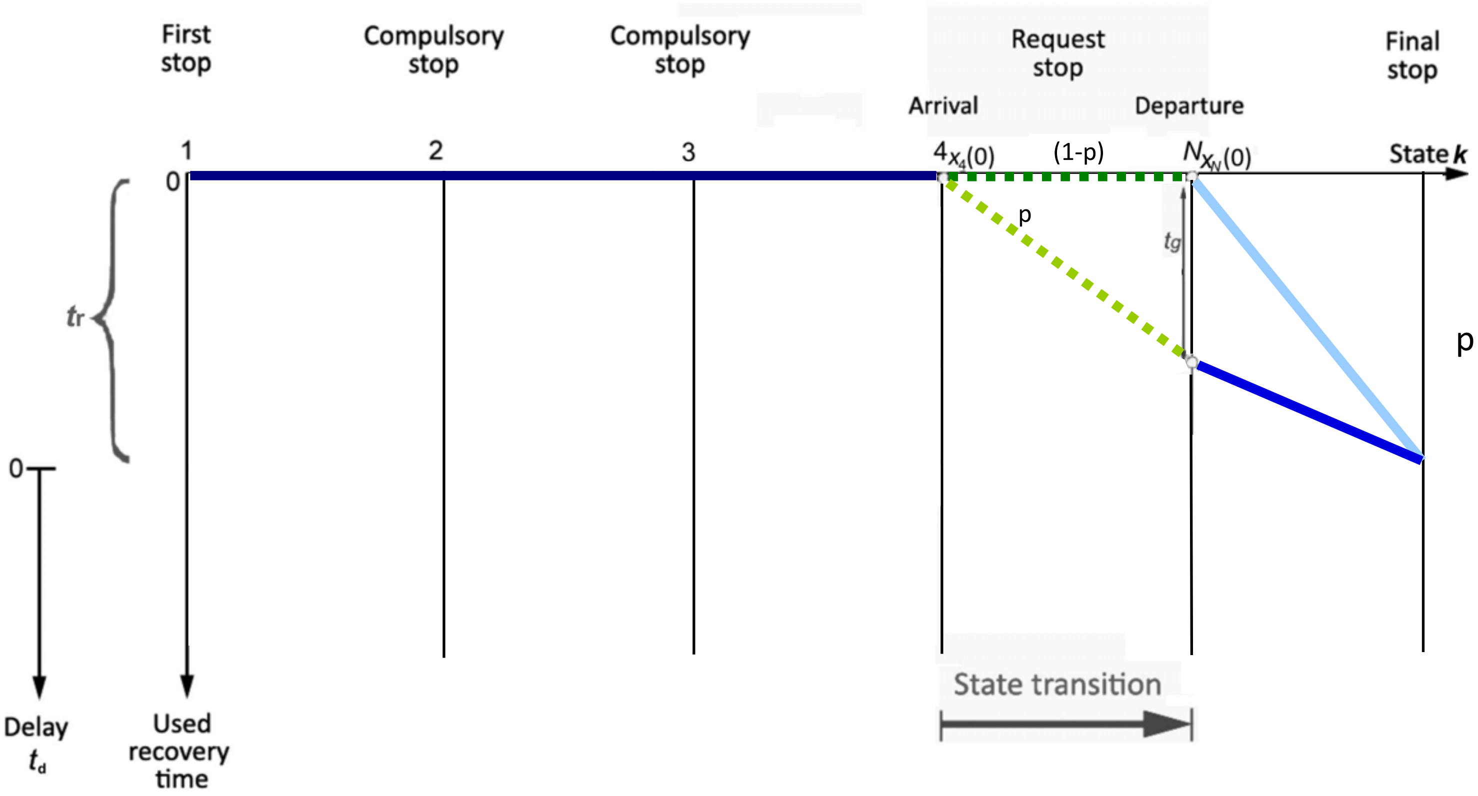
Train rides from monday to friday

without wintersport conditions



Arrival time at the final stop

Pro-active distribution strategy

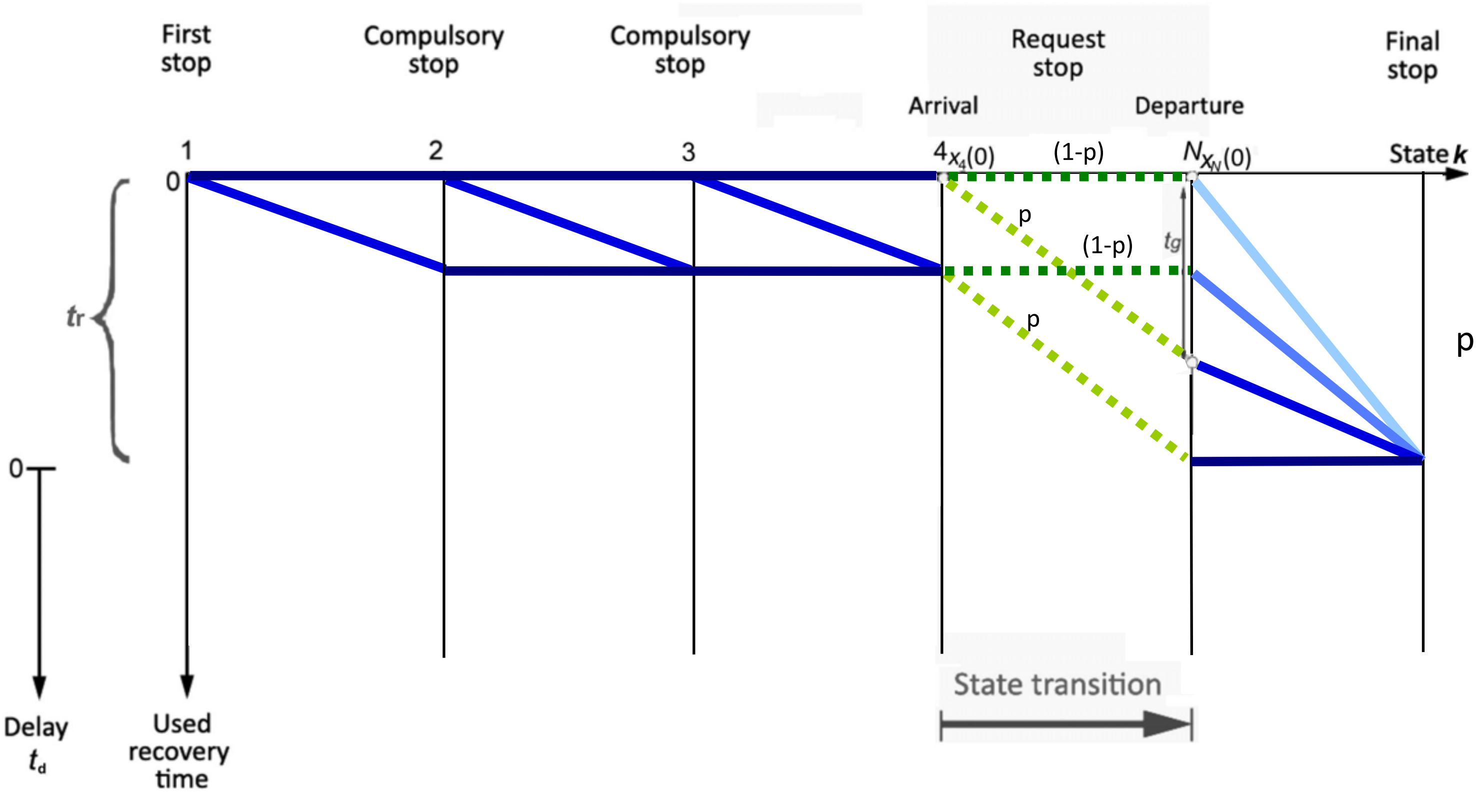


p – Stopping probability at request stop

$$Q_i(k, x_k) = p \cdot Q_i\left(k+1, x_{k+1}, z_{k+1} = t_g\right) + (1-p) \cdot Q_i(k+1, x_{k+1}, z_{k+1} = 0)$$

Cost functions Q_1 *– energy consumption;* Q_2 *– delay*

Pro-active distribution strategy



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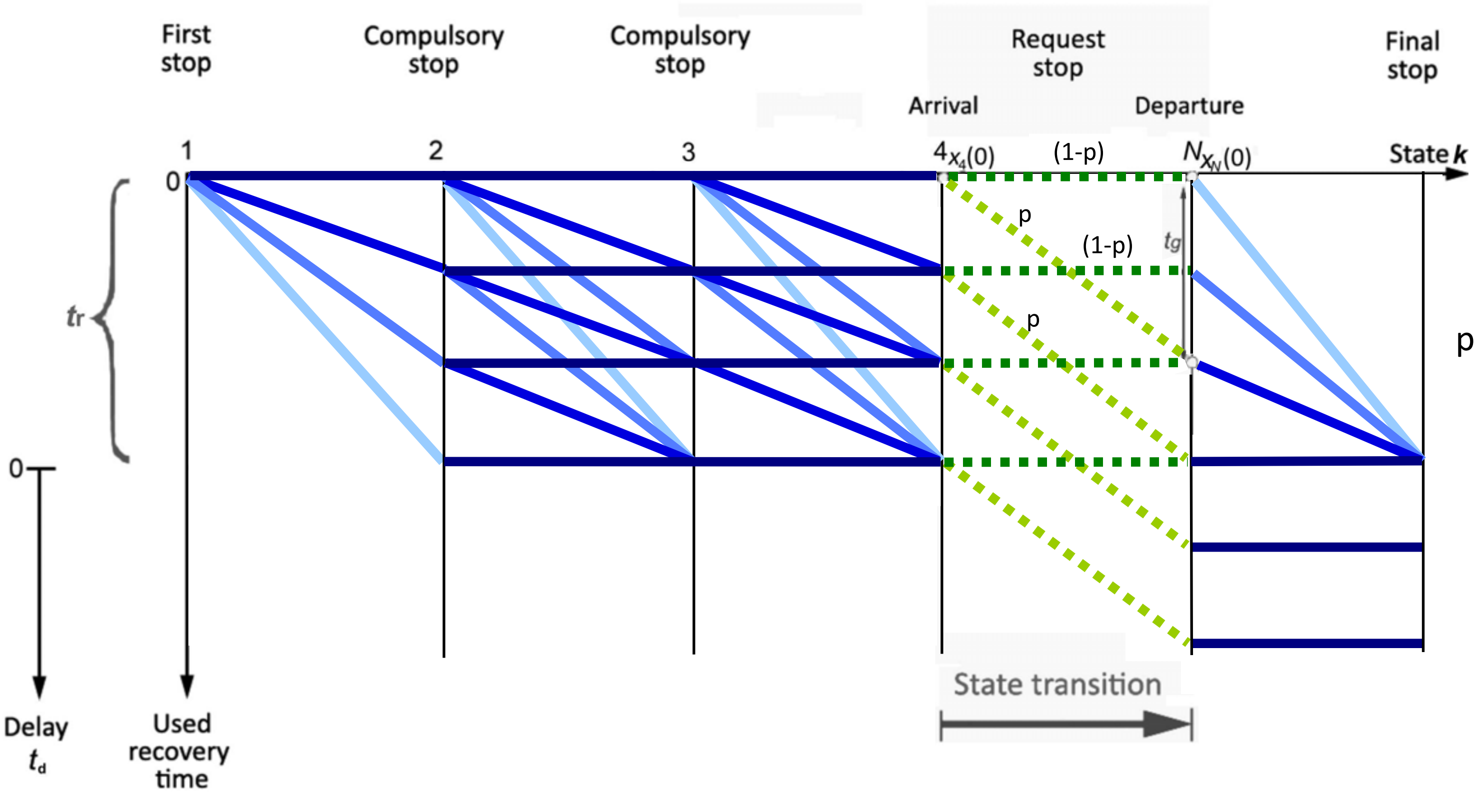

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Cost functions Q_1 *– energy consumption;* Q_2 *– delay*

4.3 Schedule-related Optimization Constraints

Classification	**Parameter**
Hard constraint	- earliest arrival fulfilling connection service - latest departure time fulfilling connection service - earliest scheduled departure time
Soft constraint	- Latest scheduled arrival time

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Hard constraint

- Deviations for the benefit of less energy consumption prohibited
- Restricted search space within Dynamic Programming

4.3 Schedule-related Optimization Constraints

Classification	Parameter
Hard constraint	- earliest arrival fulfilling connection service - latest departure time fulfilling connection service - earliest scheduled departure time
Soft constraint	- Latest scheduled arrival time

<u>Hard constraint</u>

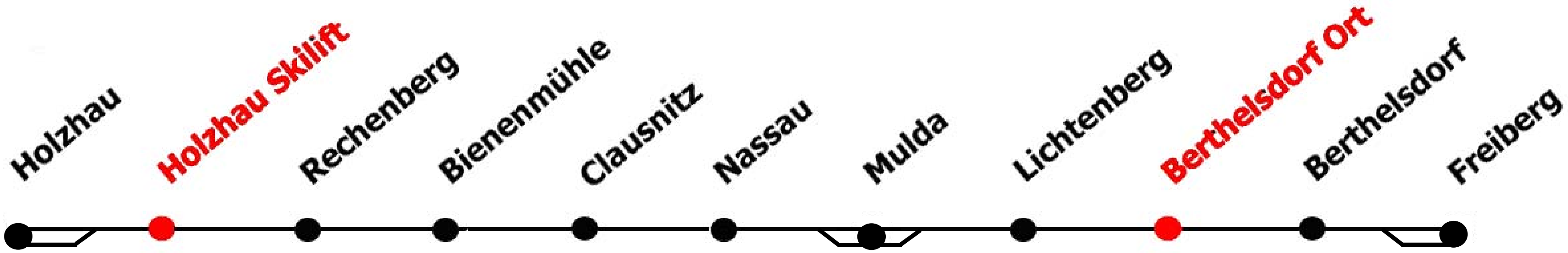
- Deviations for the benefit of less energy consumption prohibited
- Restricted search space within Dynamic Programming

<u>Soft constraint</u>

- Small delays at low frequented stops are tolerable
- Delay cost function is weighted stationwise by boarding/alighting passengers
- Trade-off cost function as a compromise between oppositional optimization goals

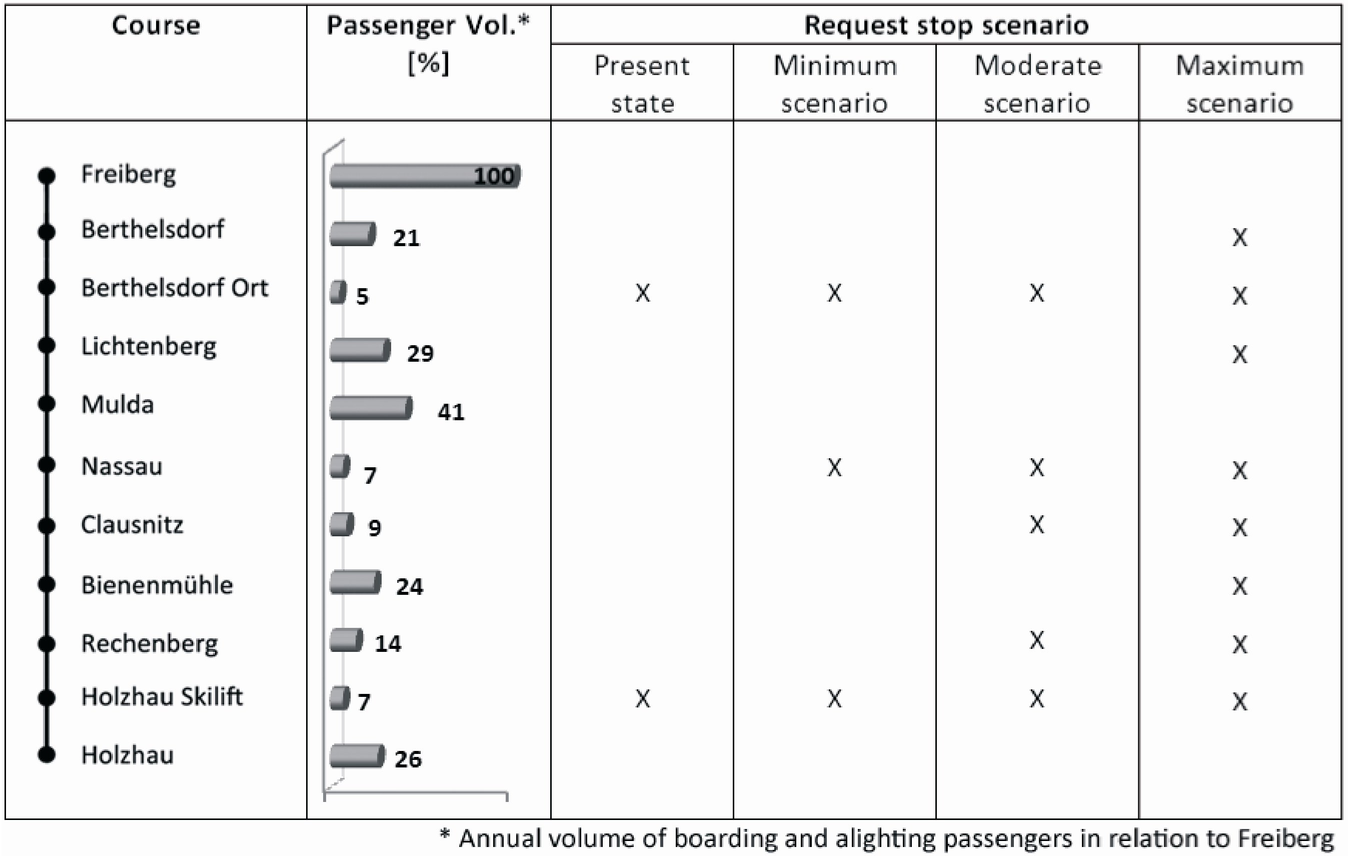
5. Case Study

- Single track line with two request stops



- Crossing station Mulda
  - Scheduled times treated as hard constraints → no interference with oncoming trains
- Train Model: DMU RegioShuttle 1 (StadlerRail)

- Simulation of 4 request stop scenarios with present time table (168 train rides)



Course	Passenger Vol.* [%]	Request stop scenario: Present state	Request stop scenario: Minimum scenario	Request stop scenario: Moderate scenario	Request stop scenario: Maximum scenario
Freiberg	100				
Berthelsdorf	21				X
Berthelsdorf Ort	5	X	X	X	X
Lichtenberg	29				X
Mulda	41				
Nassau	7		X	X	X
Clausnitz	9			X	X
Bienenmühle	24				X
Rechenberg	14			X	X
Holzhau Skilift	7	X	X	X	X
Holzhau	26				

* Annual volume of boarding and alighting passengers in relation to Freiberg

Total number of stopping events [%]	100			
Avg. energy consumption [%]	100			

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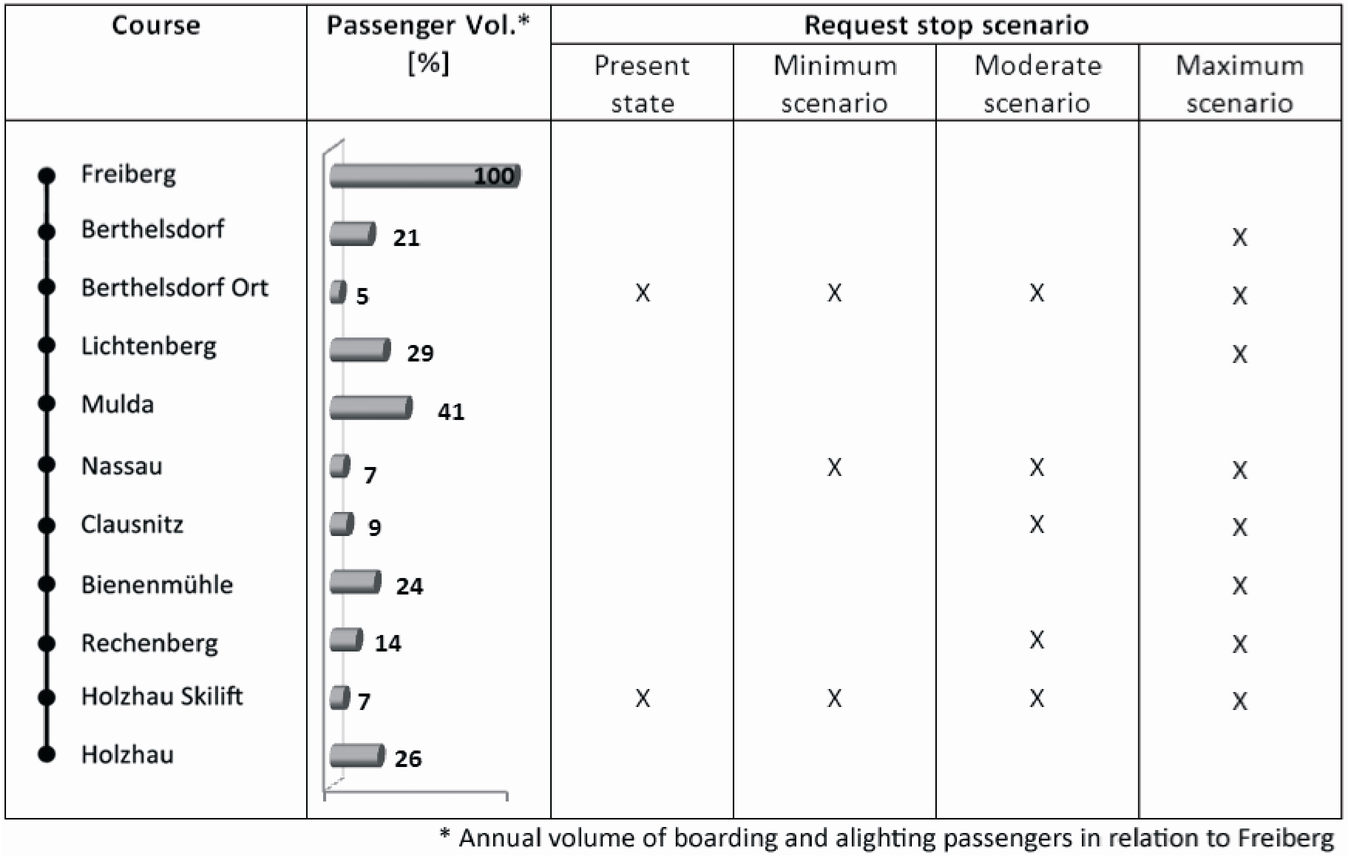

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		Present state	Minimum scenario	Moderate scenario	Maximum scenario
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Berthelsdorf Ort	5	X	X	X	X
Lichtenberg	29				X
Mulda	41				
Nassau	7		X	X	X
Clausnitz	9			X	X
Bienenmühle	24				X
Rechenberg	14			X	X
Holzhau Skilift	7	X	X	X	X
Holzhau	26				

* Annual volume of boarding and alighting passengers in relation to Freiberg

Total number of stopping events [%]	100	93	81	70
Avg. energy consumption [%]	100	95	88	81

Further results

- In spite of pro-active distribution – acceptable delays
  - No delays at important stops (crossing station; major interchange stations)
  - $t_{\mathrm{d,90}} < 30$ sec

- Slight changes in timetable allows further increases in energy efficiency

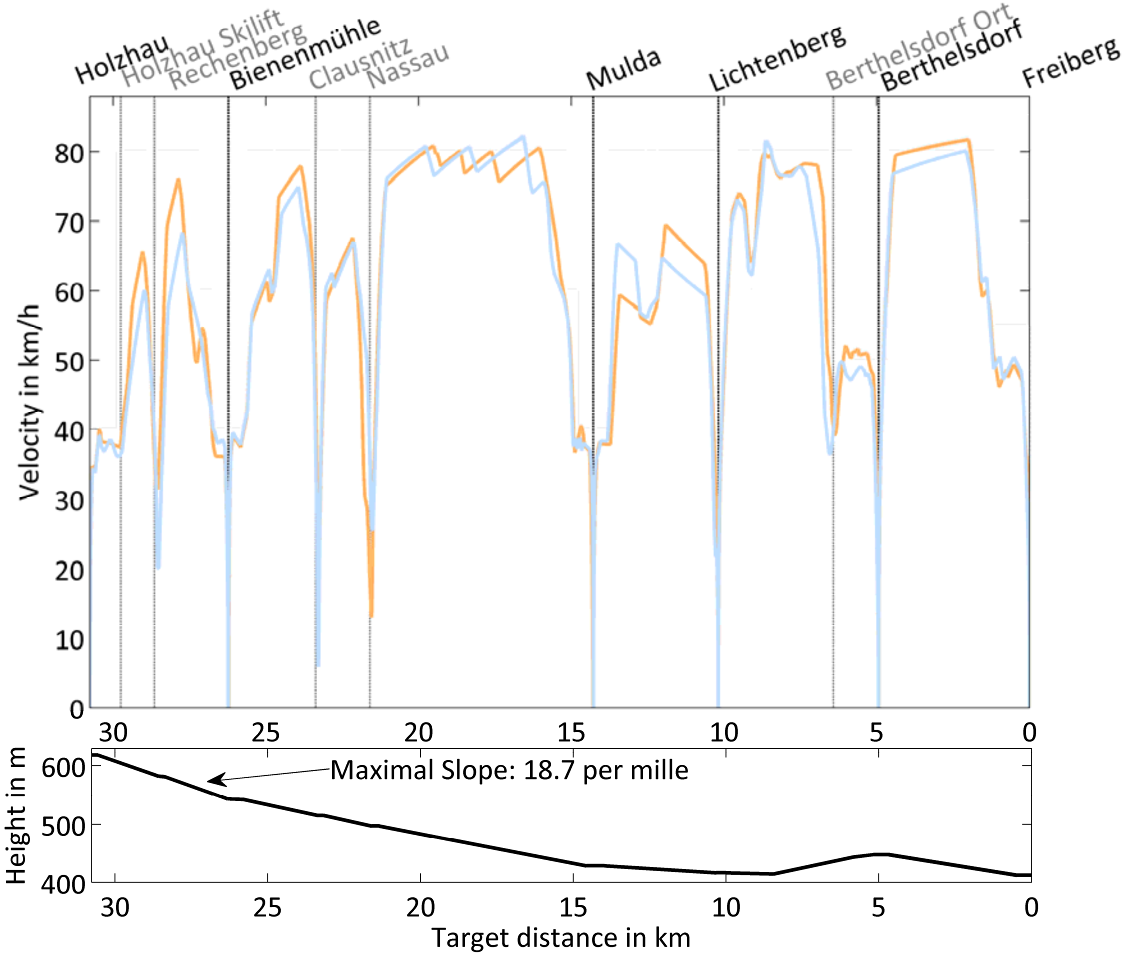
Further results

- Comparison at the TU Dresden Driving Simulator: Experienced driver **vs** Algorithm

  → Testing a line with 5 request stops (Medium scenario)

Further results

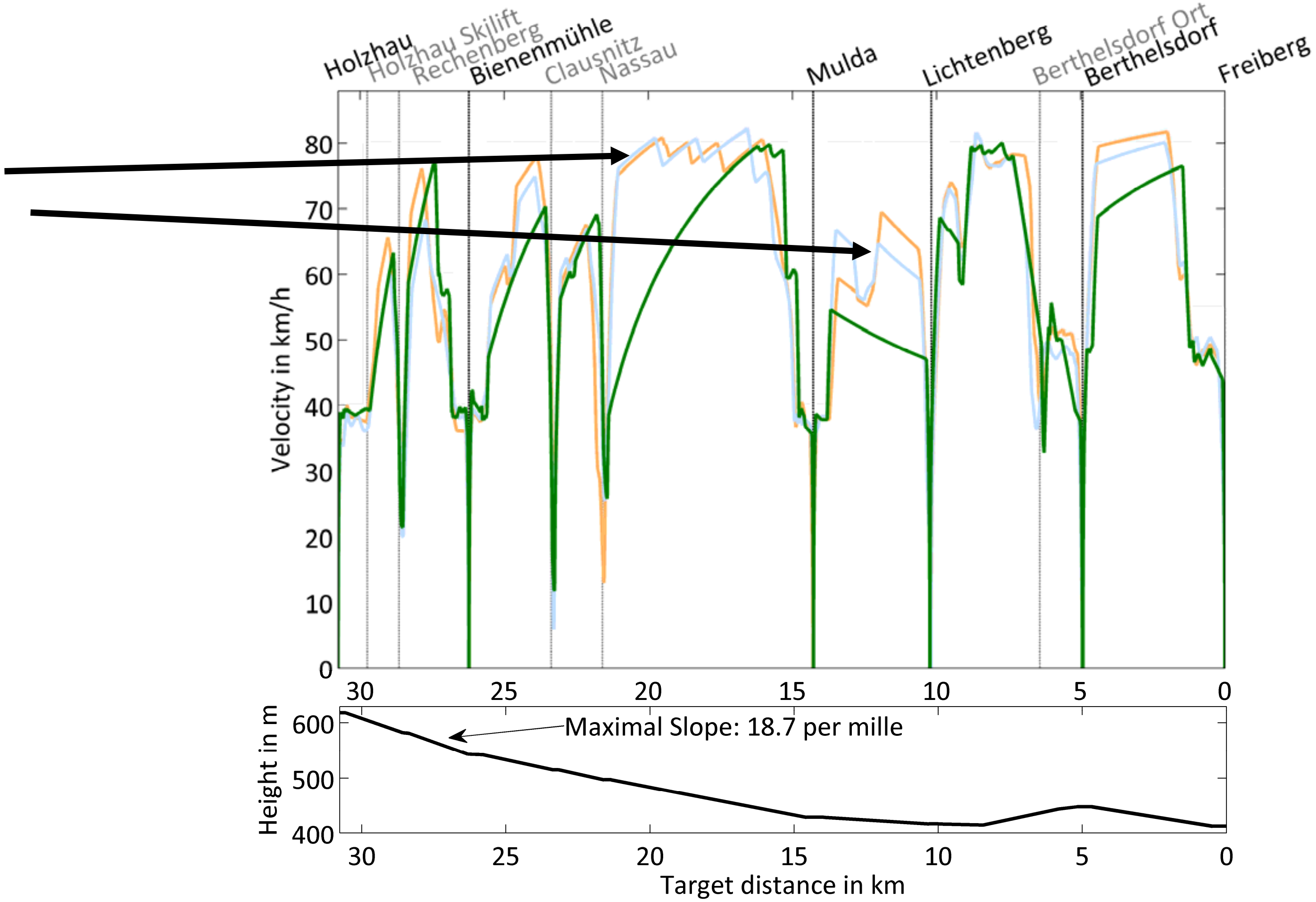
- Comparison at the TU Dresden Driver Simulator: Experienced driver **vs** Algorithm



Further results

- Comparison at the TU Dresden Driver Simulator: Experienced driver **vs** Algorithm

Driver:
Less coasting – early arrivals



Further results

- Comparison at the TU Dresden Driver Simulator: Experienced driver **vs** Algorithm

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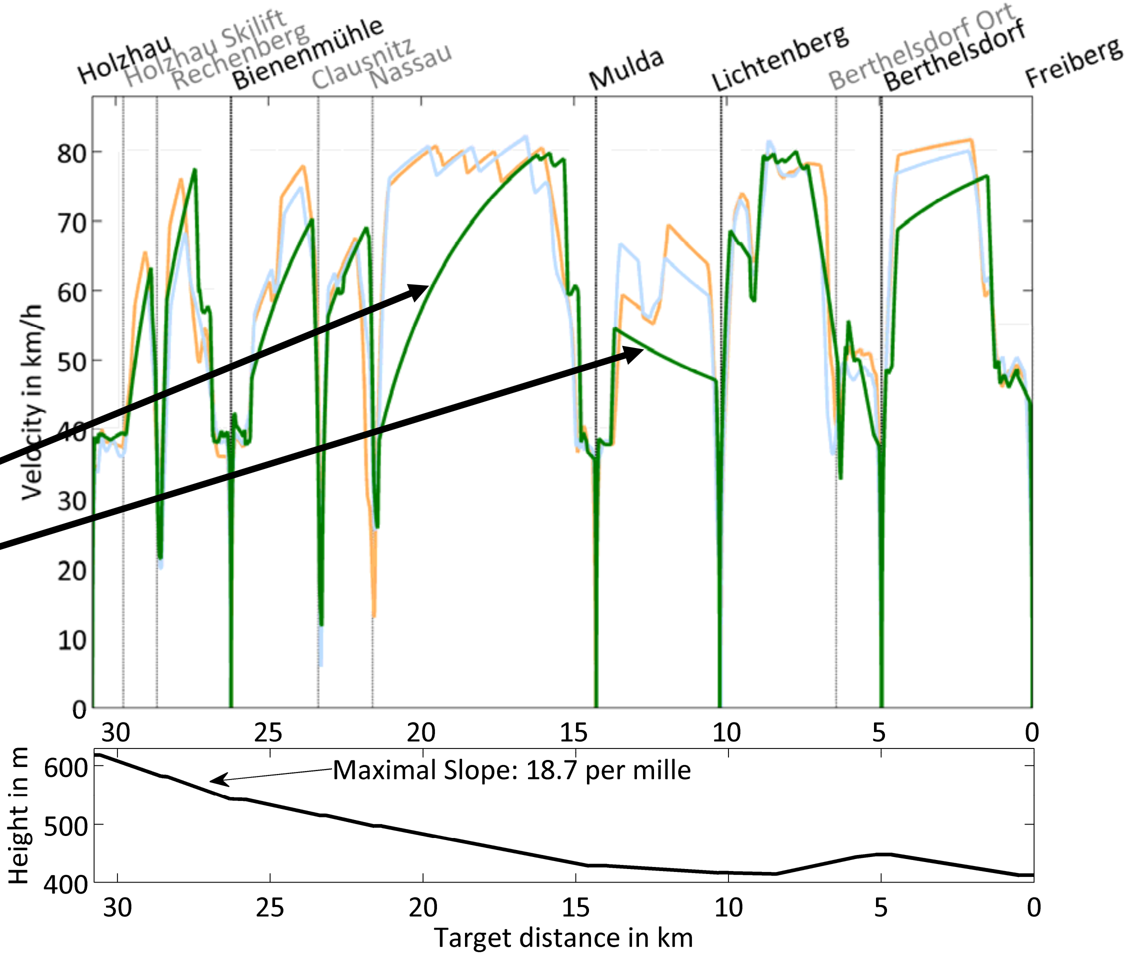
Fahrt von Dresden-Niedersedlitz
nach Dresden-Zschachwitz
Ankunft in 97 s

Höchstgeschwindigkeit 120 km/h

11:41:41; 59 km/h



Assistance:
Investing time gain in
longer ranges of coasting

→ 20% less energy consumption

6. Conclusions

- Request stops reveal a high potential of saving energy
- Taping these potentials requires an assistance system
  - probabilistic assumptions based on passenger statistics
  - pro-active distribution of time slack
- Delays can be confined effectively
  - by defining optimization constraints
  - by using a trade-off cost function (Multi-criterion Optimization)
- Energy optimization for tramway systems