The OpenTrack API - further Experiences

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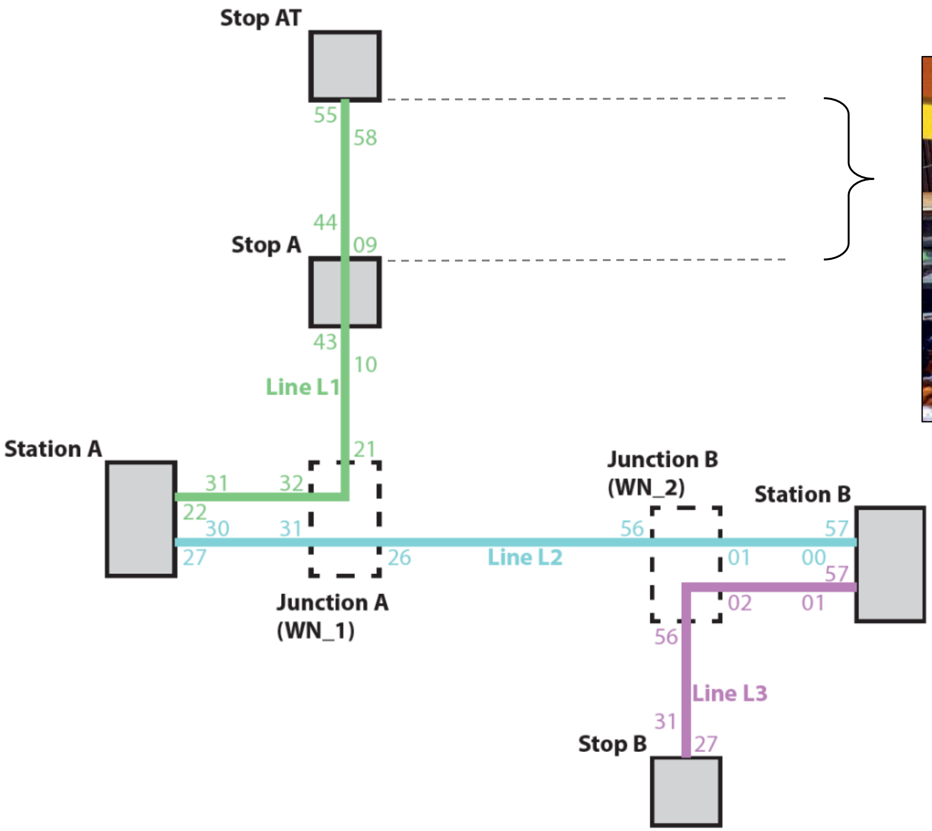
Case Study using OpenTrack for benchmarking automatically generated timetable scenarios specified by the transport service intention



Topics

1. **Basics: Timetable Planning for construction intervals**
   a. Interval planning application concept
   b. Timetabling process
   c. Use cases
   d. Service intention as functional requirement for automated scheduling service
   e. Performance indicators resulting from SII and MPPA
   f. Demonstration of lab environment
2. **Case Study**
   a. Relation between macroscopic timetabling and microscopic simulation
   b. Planning Cases for construction interval
   c. Evaluation of planning cases
3. **Summary**

Basics: Application concept: IP

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Timetable Planning for construction intervals (IP), *Requirements*:

- *Fast, computer aided development of timetable scenarios*
- *Easy assessment of timetable scenario performance.*
- *Quality assessment of timetables with respect to:*
  1. ***Customer conveniance**, of transport service offer (service intention, SI),*
  2. ***Operational feasibility and stability** of timetable scenario.*

Basics: Timetabling process as iterative computer aided decision support*

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Restrictions of the infrastructure

- macroscopic modelling of the infra–structure over nodes and links
- modelling of the safety system over headway times on lines, at stations and junctions
- minimal trip and dwell times for each train, line and station
- if desired minimal turnaround times

Functional Requirements

- desciption of train lines over a sequence of macroscopic nodes which are passed on their driving path and tracks used on the lines
- maximal trip and dwell times for each train line and station
- connections between train lines including a minimal and maximal time for transfers
- train frequencies and train separations in time
- fixation of train departure times to a given time interval

PESP:
Periodic Event
Scheduling Problem

Algorithms

hourly pattern for a macroscopic periodic timetable optimizing total passenger travel time

macroscopic time–table evaluation

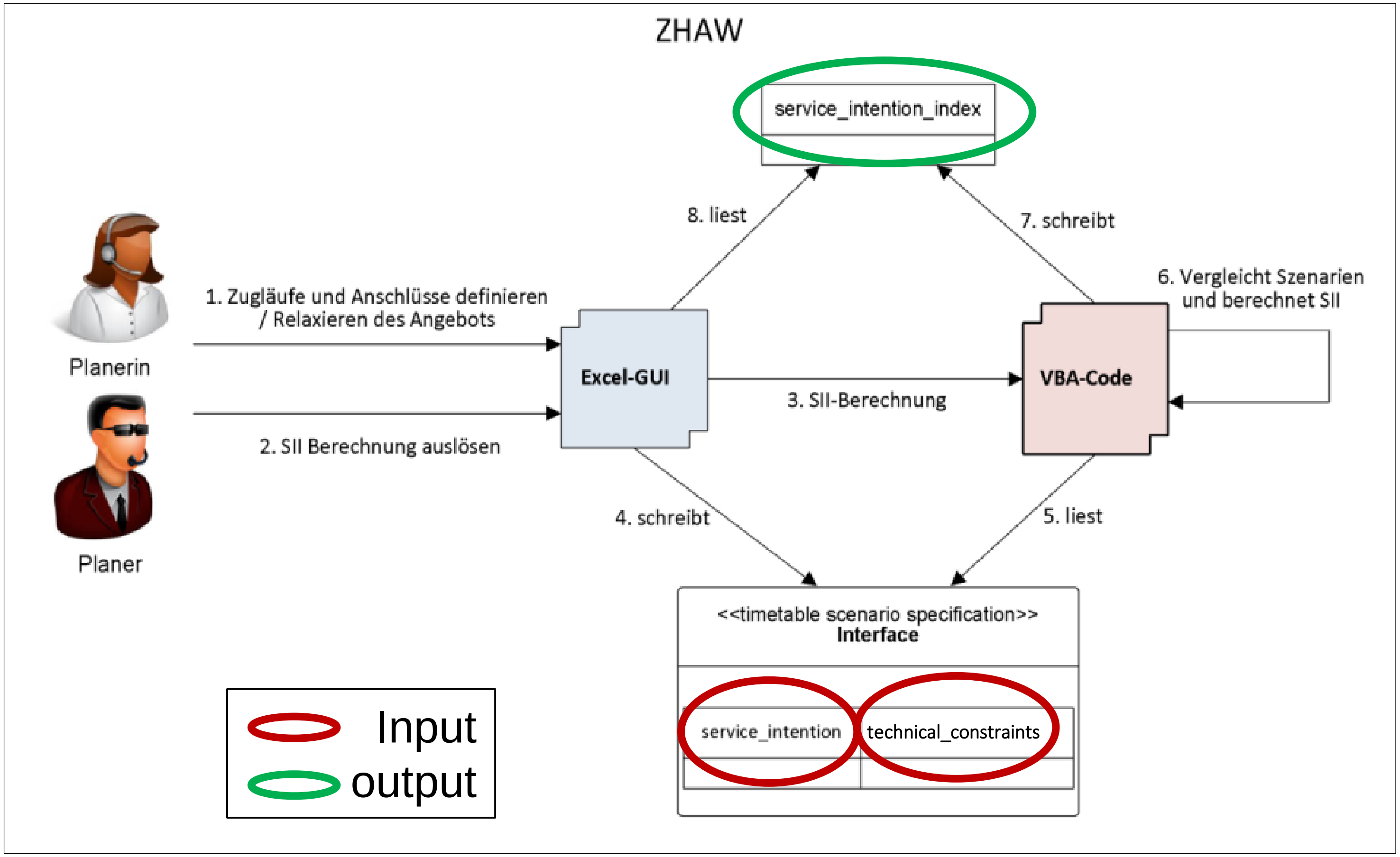
MaxPlus Algebra

manual input adatptions from planners

*Herrigel-Wiedersheim, S. (2015). *Algorithmic decision support for the construction of periodic railway timetables*, diss. ETH no. 22548,

Basics: IP application concept
Use case 1

Aim of Use Case 1: Handling of restricted infrastructure availability
In case of planned or unplanned restrictions of infrastructure, the system is required to (automatically) generate a service intention, which is customer oriented and operationally feasible.



Basics: IP application concept
Use case 2a

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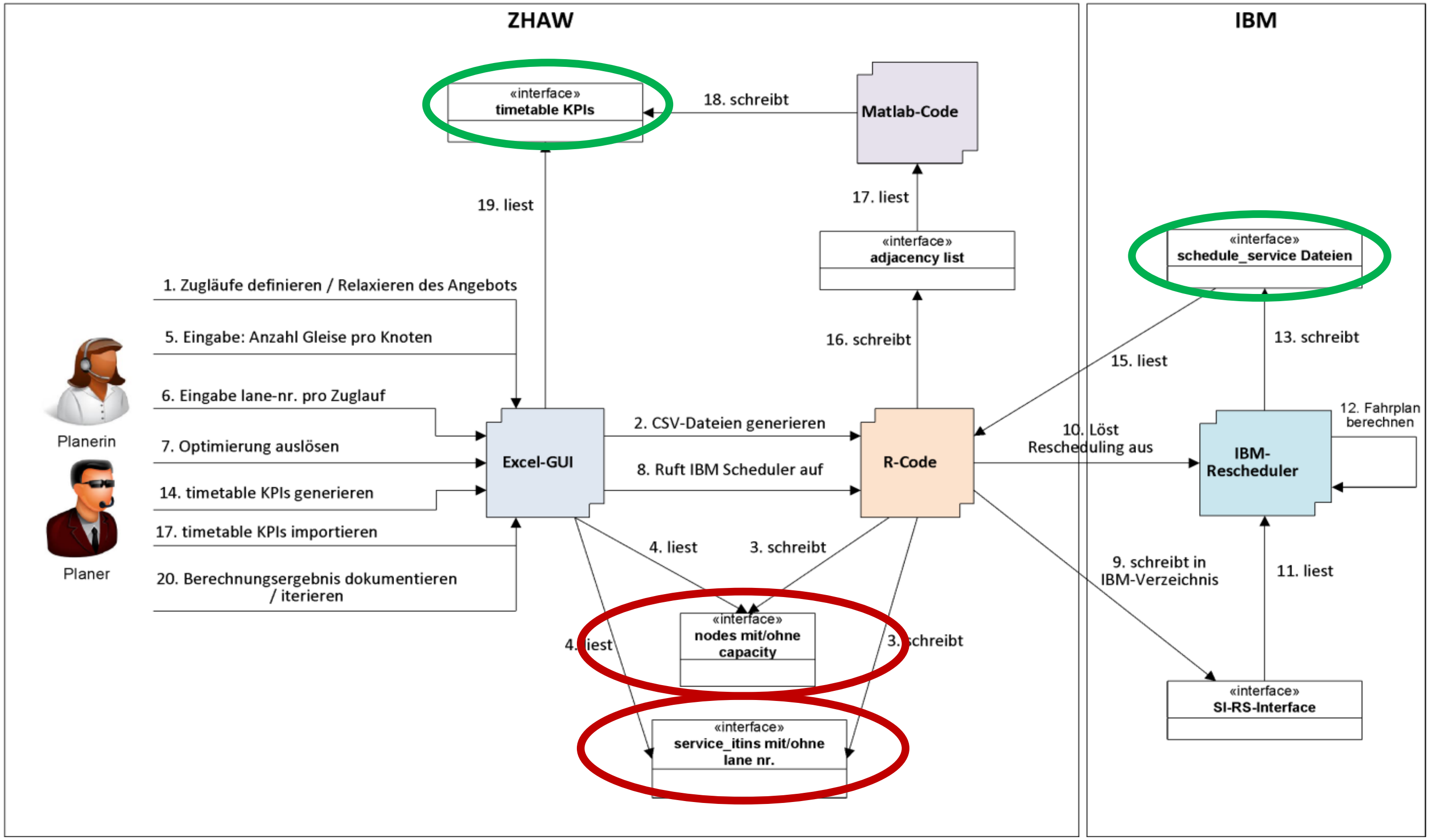
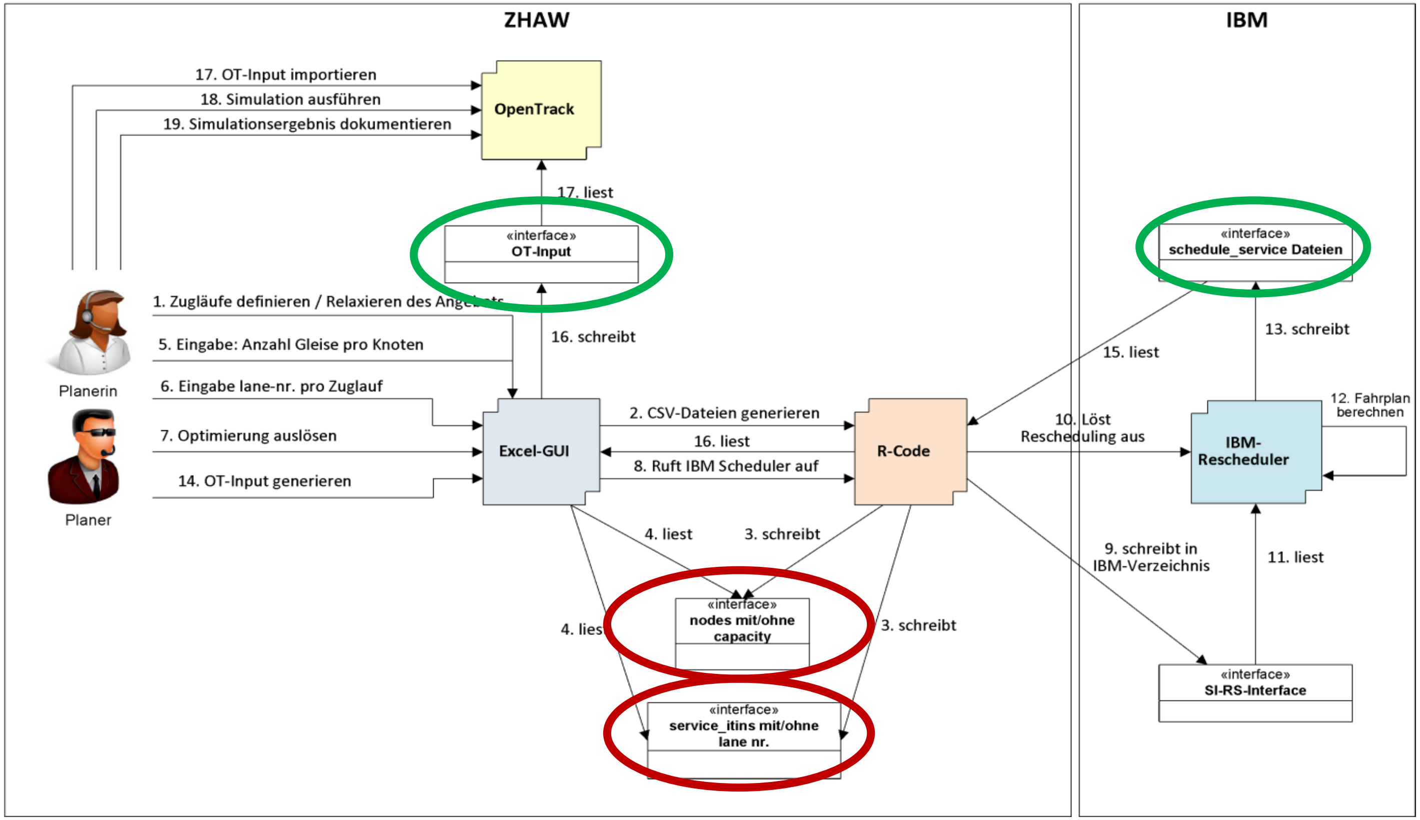
Aim of Use Case 2a, Automated Timetabling:
Given valid service intentions for input, the system is required to (automatically) generate timetable scenarios which can be assessed quantitatively in terms of operational stability



Basics: IP application concept
Use case 2b

Aim of Use Case 2b, Simulative Validation of operational feasibility and stability:
Customer orientation and operational feasibility of automatically gerenerated timetable scenarios should be validated on a microtopological resolution with the help of OpenTrack.



Basics: Service Intention (SI) as Input for IBM TraMP

Functional Specification of Schedule

- partial periodic service intention (short ppSI)

Set of operational dependencies

$$\tilde{G} = \left(Z, C, D, \overline{\rho}\right)$$

Set of all train runs

Considered period length

Set of all connections (transfer times)

- Single train run

  (Train type, stopping stations, dwelltimes, section trip times, $\boldsymbol{\omega}$ **service slot**, periodicity, number of repititions)

$$z = \left(\tilde{z}, \left(v_k, t_{\text{dwell}}^{k-}, t_{\text{dwell}}^{k+}, t_{\text{trip}}^{k-}, t_{\text{trip}}^{k+}, \omega_k^{-}, \omega_k^{+} \right)_{k=0}^{K}, \rho, R \right)$$

- Transfer times

  (Train runs, stopping station, r_i-th repetition of train run z_i, $\boldsymbol{\theta}$ maximum connection time)

$$c = (z_1, z_2, v, r_1, r_2, \theta^+)$$

(Caimi, G.C. (2009) PhD Thesis)

Basics: User Interface

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UI-Table *Service* (TrainRun)

Service ID	Train RunNr	Sta_A	WN_A	Stp_A	Stp_AT	Stp_B	WN_B	Sta_B	LineType	Rolling Stock	Periodicity	Repeat	Periode
1	10	00:31	00:32	00:45	00:56				SB	1x DPZ	60	2	8
2	11	01:24	01:21	01:10	00:59				SB	1x DPZ	60	2	8
3	20	00:29	00:26				00:01	00	IR	IC 2000 259m	60	2	8
4	21	00:30	00:31				00:56	00:59	IR	IC 2000 259m	60	2	8
5	30					00:29	00:02	00:01	SB	1x DPZ	60	2	8
6	31					00:31	00:56	00:59	SB	1x DPZ	60	2	8

UI-Tabelle *Turnarounds* (Transition of TrainRuns)

Turnaround ID	OperationPoints	TrainRunNr		MinTurnaround Time	r1	r2	cyclic
		From	To				
1	Stp_AT	10	11	2	1	1	1
2	Sta_A	20	21	2	1	1	1
3	Stp_B	30	31	2	1	1	1
4	Sta_A	11	10	1	1	2	1
5	Sta_B	21	20	1	1	2	1
6	Sta_B	31	30	1	1	2	1

Basics: Service Intention (SI) in graphical timetable

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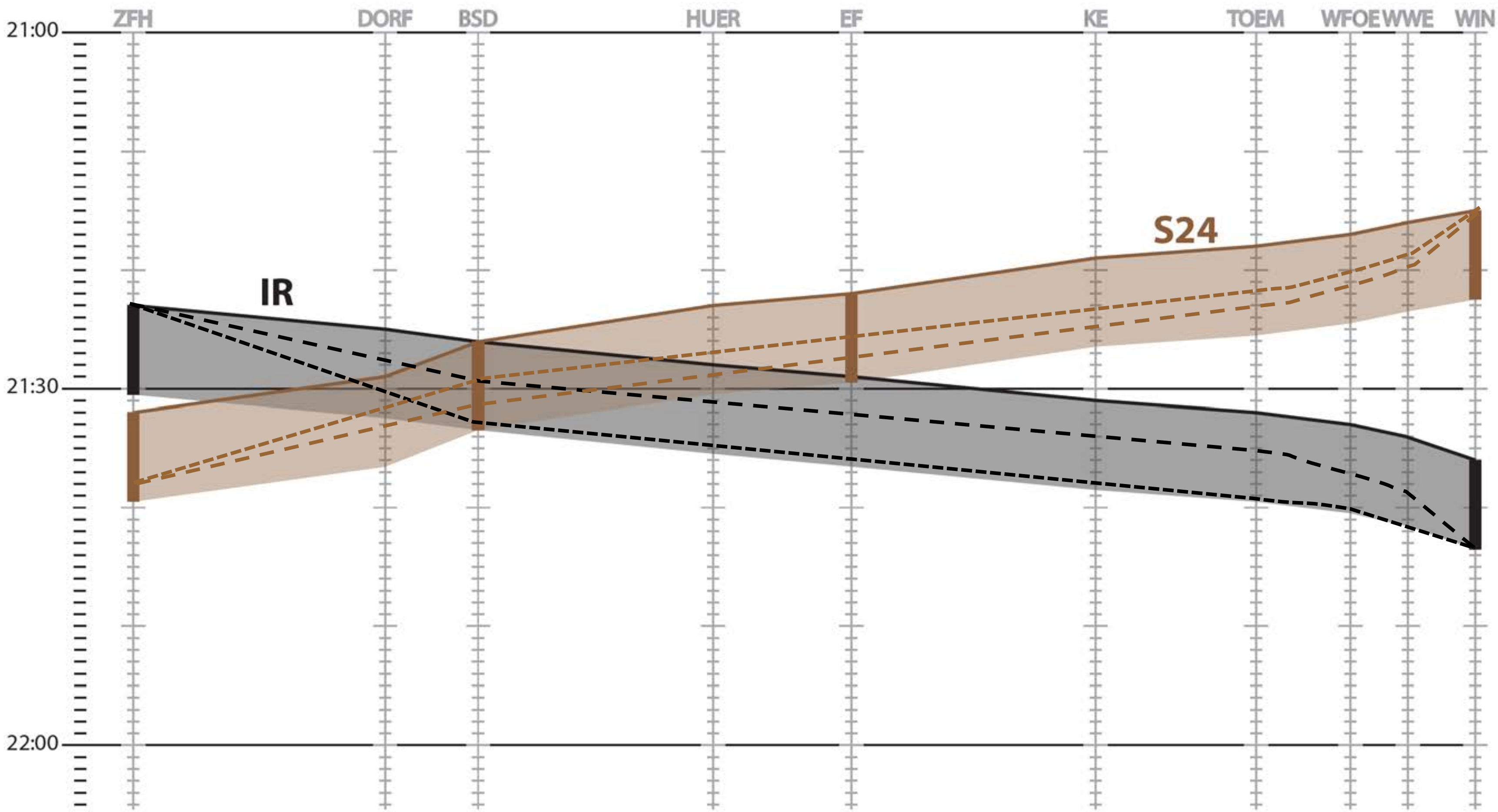

Example SI-timeslot for corridor Zürich Airport – Winterthur

Basics: SII as Performance Indicator for Customer conveniance

Service Quality: SI-Index (SII)
Performance Indicator, referring to the Service Time Spent per Period STSpP of the transport service:

$$\mathrm{SII} = \frac{\mathrm{STSpP}^{\mathrm{Plan}}}{\mathrm{STSpP}^{\mathrm{Dispo}}}, \mathrm{SII} \in [0,1]$$

SI-Index (SII), number between 0 and 1, indicating the relative distance to the original service intention.

Planned Service Time Spent per Period ($\mathrm{STSpP}^{\mathrm{Plan}}$),
The originally planned SI-travel time per (timetable-) period in [eight$^{\mathrm{th}}$'s of hours]

Realized Service Time Spent per Period ($\mathrm{STSpP}^{\mathrm{Dispo}}$),
The SI-travel time per (timetable-) period in [eight$^{\mathrm{th}}$'s of hours] for the IP scenario

Basics: Case Study $STSpP^{Plan}$

Accesspoint Departure	ZugNr / Connection	Segment Nr	Accesspoint Arrival							STSpP (ZP)	STSpP (Tot)
			Sta_A	WN_A	Stp_A	Stp_AT	Stp_B	WN_B	Sta_B		
Sta_A	10			0	3	4				7	**136**
Sta_A	21			0				0	4	4	
Sta_A	**A4**						9	0		9	
Sta_B	20		4					0		4	
Sta_B	**A2**				7	8		0		15	
Sta_B	30						4	0		4	
Stp_A	10					2				2	
Stp_A	11		3	0						3	
Stp_A	**A1**						12	0	8	20	
Stp_AT	11		5	0	2					7	
Stp_AT	**A1**							0	10	10	
Stp_AT	**A1-A4**						13	0		13	
Stp_B	31							0	4	4	
Stp_B	A3		9	0				0		9	
Stp_B	A3-A2			0	12	13		0		25	

Case Study: Result of Calculation $STSpP^{Plan}(Tot) = \mathbf{136}$

Basics: Modeling of Timetable

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Timetable generation

Defined by **periodic timetable vector** (result of TraMP) $\boldsymbol{d_i^0}$.

d_i^0 indicates the timestamp of event i in period k, with $d_i^0 \in [0, T)$.

Required solution: timestamp of event i in an arbitrary period $k = 0,1,\ldots$ is calculated as follows:

$$\boldsymbol{d_i(k) = d_i^0 + k \cdot T}$$

Restrictions

a. Process event and timetable event

Any event i should **not occur before** the time of the corresponding timetable event:

$$\boldsymbol{x_i(k) \geq d_i(k)}$$

Basics: Modeling of Timetable

b. Consideration of preceding events

Considering the **minimal process time** of a process (j, i) given the timestamp of it's start event x_j the following condition must be satisfied:

$$x_i(k) \geq a_{ij} + x_j(k - \mu_{ij}),$$

The period shift μ_{ij} is defined through the initial timetable event time d_0, the minimal process time duration a_{ij} between events i, j and the timetable period T by the following equation:

$$\mu_{ij} = \frac{a_{ij}^0 + d_j^0 - d_i^0}{T} \in \mathbb{N}_0$$

$\boldsymbol{\mu_{ij}}$ indicates, if between event j and i occurs (one or several) **period transitions**. Index 0 represents the first occurance.

Basics: Input for Performance calculation MPPA

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c. Critical cycle

Based on the periodicity of a discrete event system, there exists at least one cycle, which is defined by a ***sequence of events, which leads backwards from any event $\boldsymbol{i}$ to it's (periodically) originating event $\boldsymbol{i-T}$***.

The critical cycle is exactly that cycle of the system which has the maximum mean duration, which corresponds in the mathematical sense to the highest eigenvalue of the system (e.g. Goverde 2010).

The **maximal average cycle time $\boldsymbol{\lambda}$** is calculated as follows:

$$\boldsymbol{\lambda = \max_{\xi \in C} \frac{w(\xi)}{\mu(\xi)}}$$

C represents the the set of all cycles of the DE system, ξ indicates one of these cycles, $w(\xi) = \sum_{(j,i)\in\xi} a_{ij}$ represents the sum of all process times a_{ij} (between events j and i) belonging to that cycle and $\mu(\xi) = \sum_{(j,i)\in\xi} \mu_{ij}$

Basics: MPPA (Max Plus Performance Analyser), Performance measures

d. Eigenvalue and Eigenvector of DE System and Stability

Solving the Eigenvalue problem with respect to the quadratic state matrix $A \in \mathbb{R}_{\max}^{n \times n}$ results in the scalar value $\lambda \in \mathbb{R}_{\max}$ als well as a corresponding vector $v \in \mathbb{R}_{\max}^{n} \backslash \{\varepsilon\}$, satisfying (in Max-Plus-Notation) the following equation:

$$A \otimes v = \lambda \otimes v$$

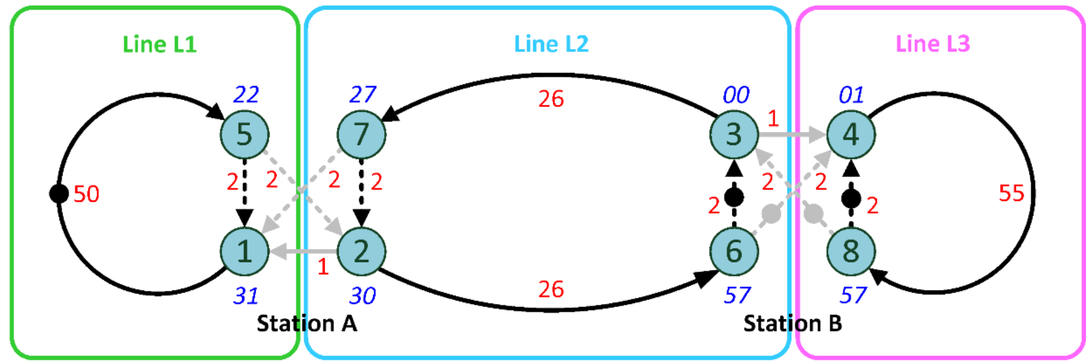
$\lambda = \lambda(A)$ refers to the eigenvalue and v to the corresponding (right) eigenvector. Based on the **Eigenvalue λ_0 of the critical cycle**, the **stability of the system** can be characterised quantitatively by **three different cases**:

$\lambda_0 < T \rightarrow$ the system is **stable**

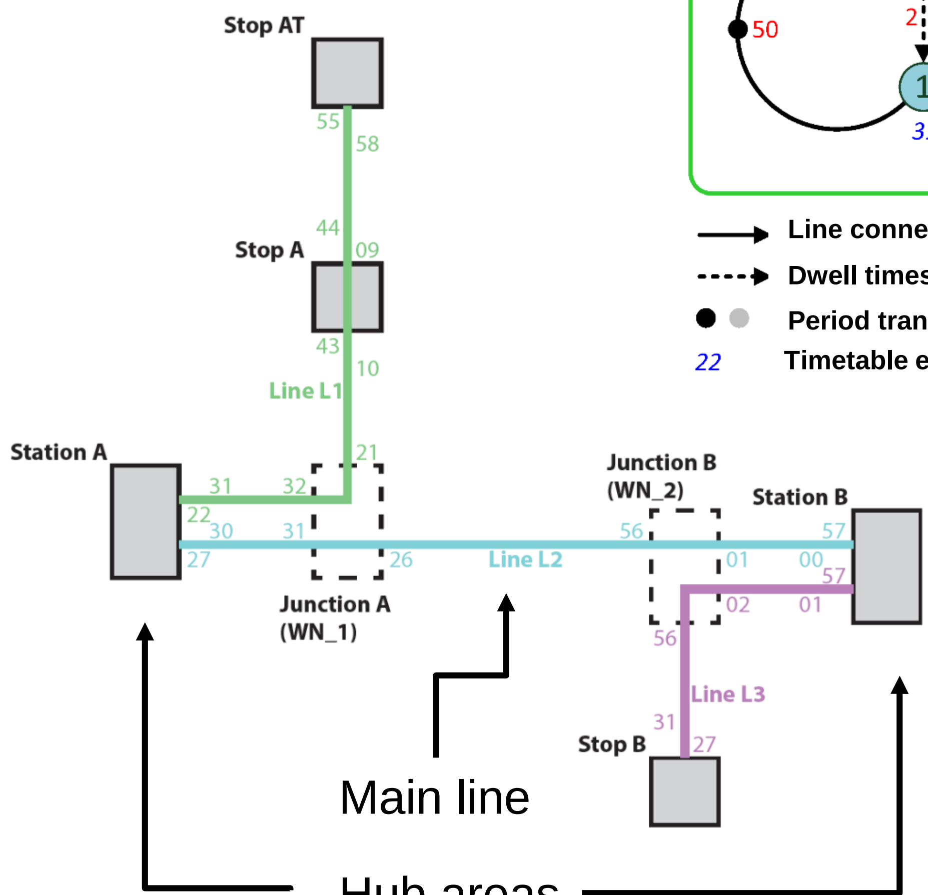
$\lambda_0 \approx T \rightarrow$ the system is **critical**

$\lambda_0 > T \rightarrow$ the system is **instable**

Case Study: «MaxplusHausen»*
Macro topological representation



- Line connections (line L1 to L3)
- Dwell times
- Period transitions
- *22* Timetable event times (minutes)
- Headways
- Changeover times
- 50 Minimum process times (minutes



*Goverde, R.M.P. (2007). Railway timetable stability analysis using max-plus system theory. Transportation Research Part B, vol. 41, no. 2, pp. 179–201

Case Study: reference case A and micro topological representation

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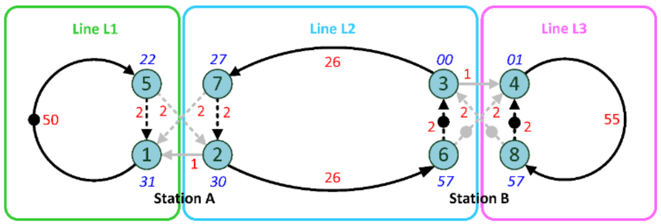
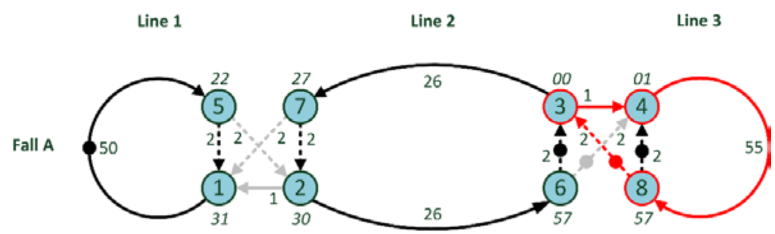
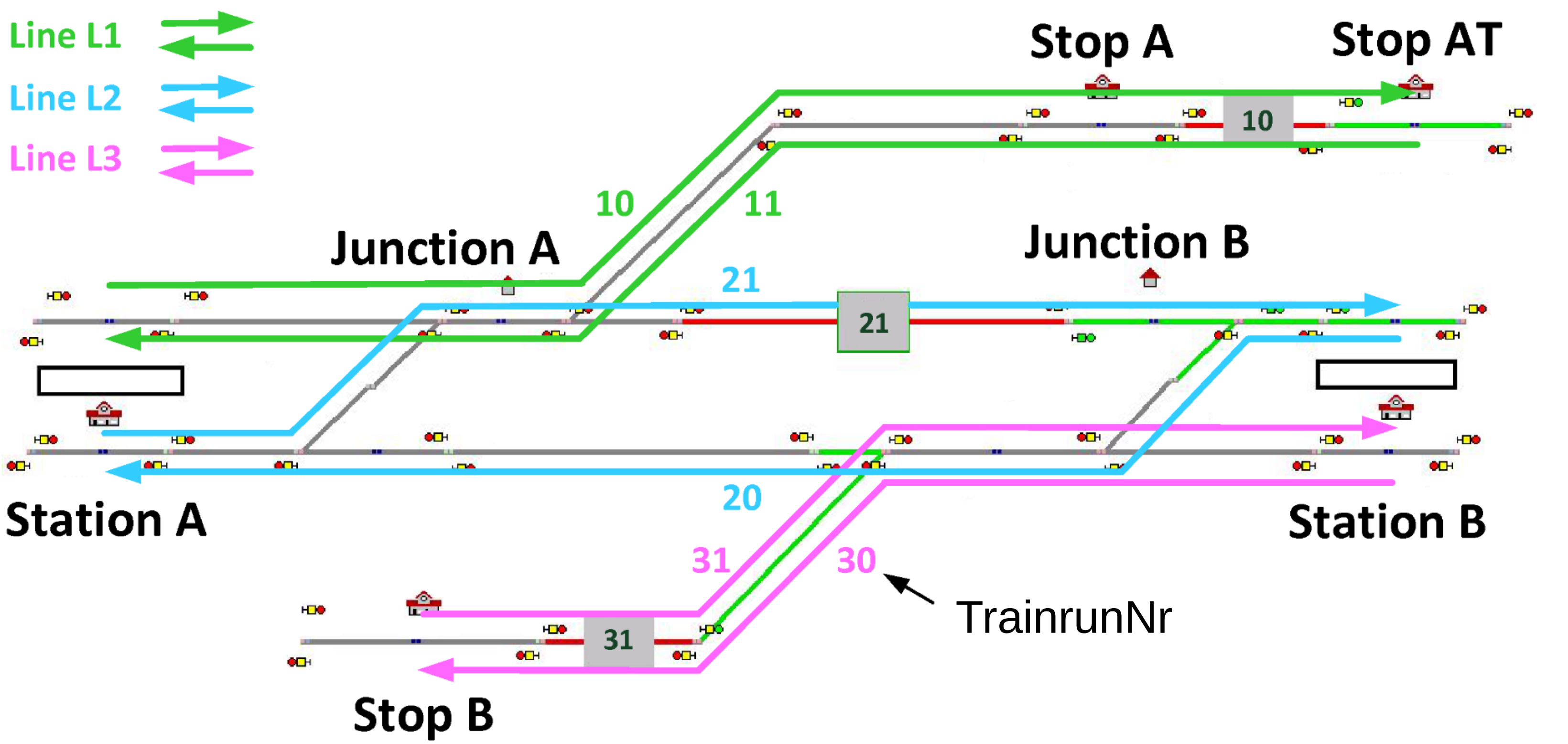


Critical cycle: base plan (case A)





Case study: comparison of four scenarios

Case A: Reference timetable

Case B: Reference timetable with restrictions of interval

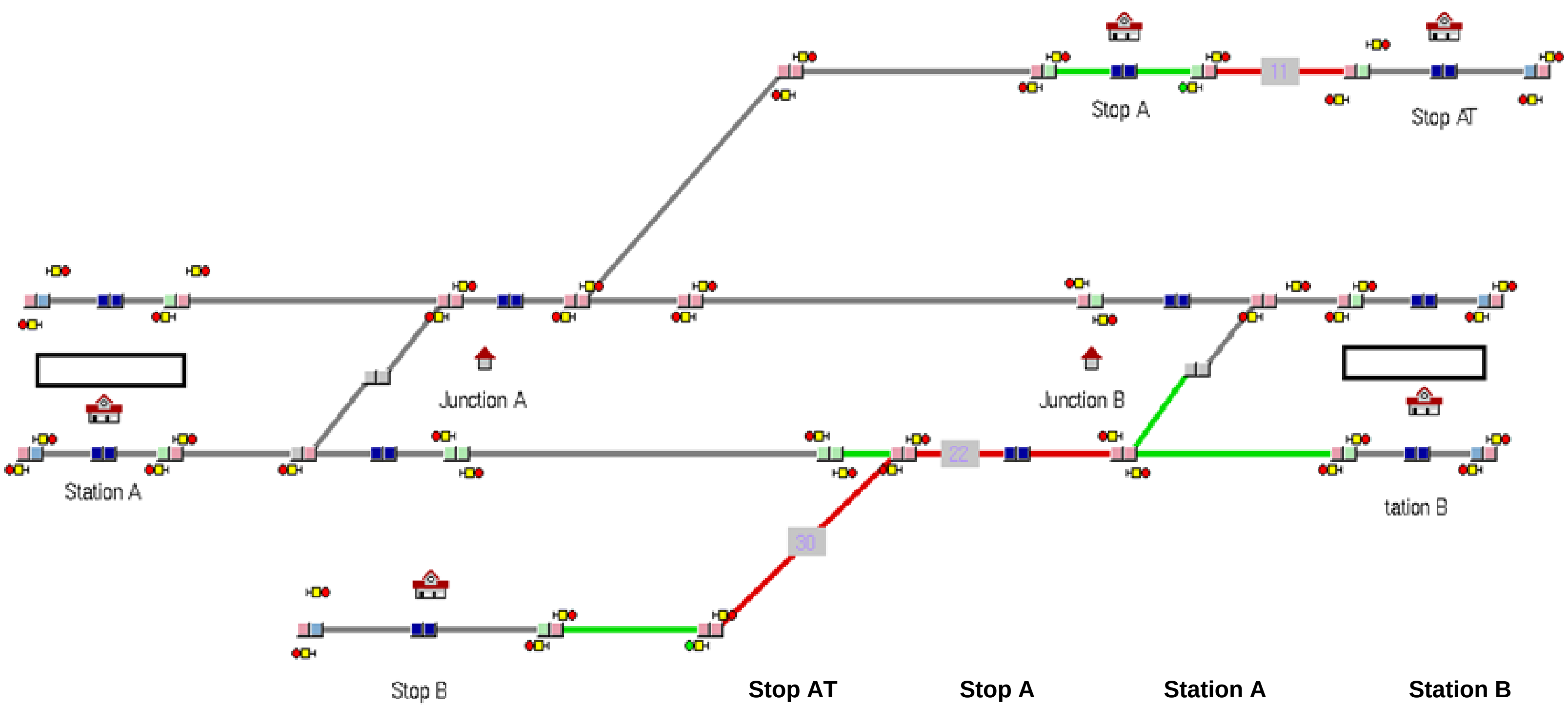
Case C: SI-Solution for interval with broken connection

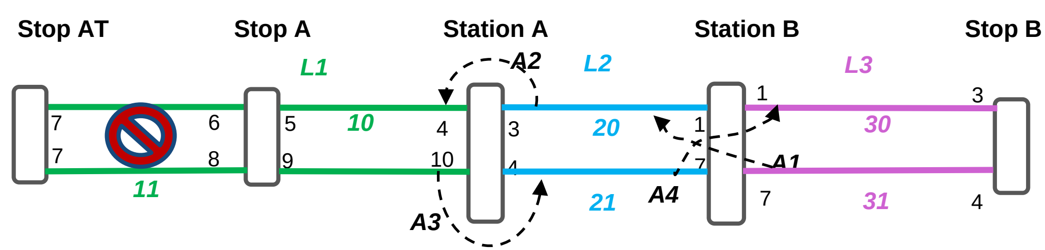
Case D: SI-Solution for interval with shifted turnaround, no service of Stop AT

Case Study: Case B
situation of construction interval

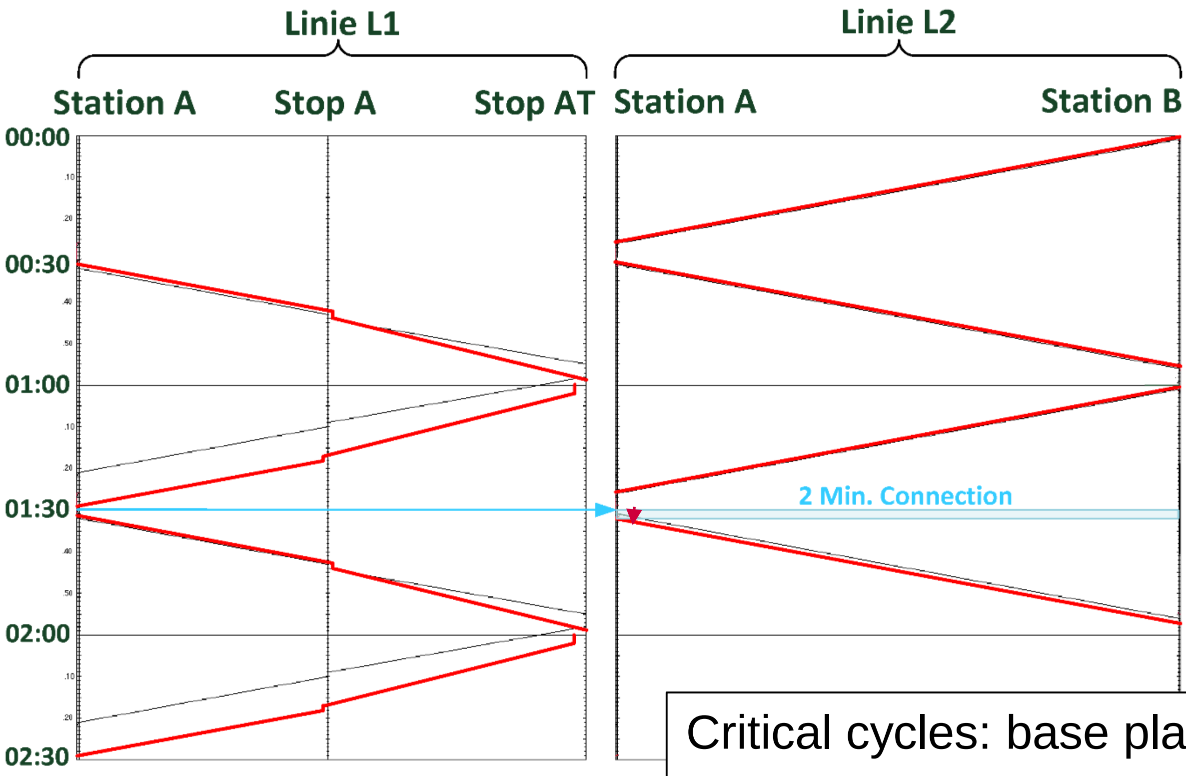
Interval situation

Simulation snapshot of original timetable with reduced trackspeed in section between Stop A and Stop AT.

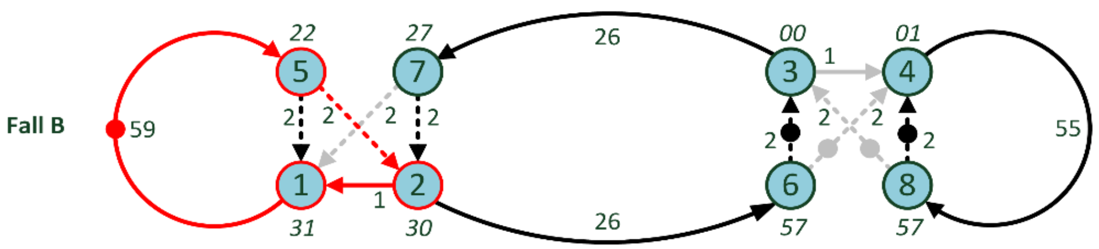




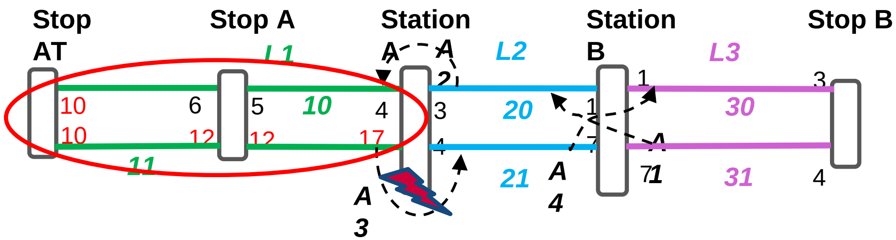
Case Study: Case B
situation of construction interval

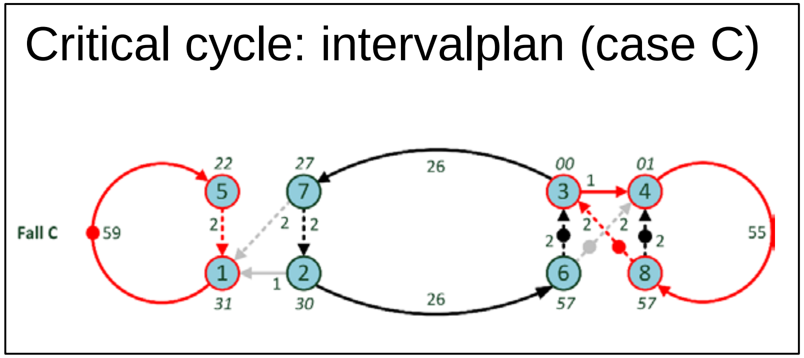


Critical cycles: base plan with interval (case B)



Case Study: Case C
scenario with broken line connection





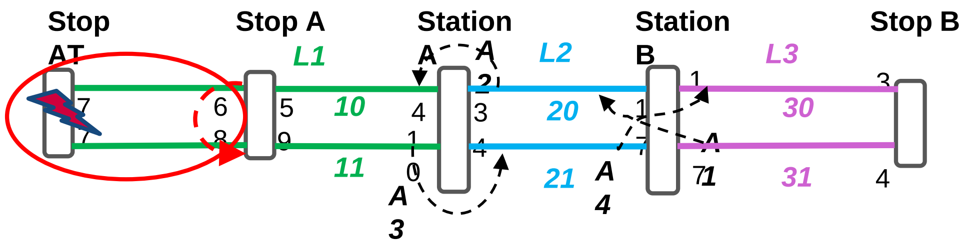
ServiceID	TrainRun Nr	Sta_A	WN_A	Stp_A	Stp_AT
1	10	00:31	00:32	00:45	01:09
2	11	01:48	01:45	01:34	01:12

Service Table: Adaptation of SI-Departure ***timeslots for services 10 and 11*** of Line 1 in order to reflect the situation with ***reduced track speed*** between operation points Stop_A und Stop_AT.

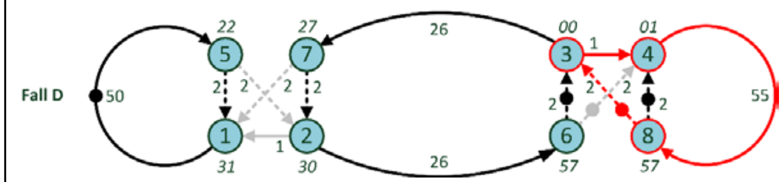
Connection ID	Operation Points	TrainRunNr		deleted	SI-Komponenten	
		From	To	(1 = yes, 0 = no)	from	to
1	Sta_A	11	21	1	6	10
2	Sta_A	20	10	0	9	1

Connection table: broken ***connection from Line 1 to Line 2*** in Station A (Sta_A) by setting the 'deleted'-Flag in the row for ConnectionID = 1

Case Study: Case D
scenario with shifted turnaround



Critical cycle: intervalplan (case D)



ServiceID	TrainRun Nr	Sta_A	WN_A	Stp_A	Stp_AT
1	10	00:31	00:32	00:45	cancelled
2	11	01:24	01:21	01:10	cancelled

Service Table: ***Stop AT is not served*** for one tt-Period. The SI-Departure timeslots for services 10 and 11 of Line 1 are deleted in order to represent the shifted turnaround to operation point Stop_A.

Turn around ID	Operation Points	TrainRunNr		MinTurnaround Time	r1	r2
		From	To			
1	Stp_A	10	11	20	1	1
2	Sta_A	20	21	2	1	1

Turnaround table: The entry for the corresponding turnaround of the line 1 is ***transferred from operation point Stop_AT to operation point Stop_A***

Case study: summary of different cases

Case	Assessment from operaional point of view				Assessment from point of view of customer convenaince
	Eigenvalues of critical cycles		Stability	Buffer time	Service intention index (SII)
	λ_1	λ_2			
A	58 Min.	-	stabil	+2 Min.	1.00
B	62 Min.	-	instabil	-2 Min.	0.83
C	61 Min.	58 Min.	instabil	-1 Min.	0.60
D	58 Min.	-	stabil	+2 Min.	0.69

Case A: Reference timetable

Case B: Reference timetable with restrictions of interval

Case C: SI-Solution for interval with broken connection

Case D: SI-Solution for interval with shifted turnaround, no service of Stop AT

Summary

- The introduced methods are suitable for timetable planning with computer aided decision support
- The introduced methods allow for quick and easy quality assessment of timetables with respect to:
  - Customer conveniance, of transport offer (service intention, SI),
  - Operational feasibility and stability of timetable scenario.
- There exists a clear mapping between macroscopic timetable modelling and microscopic simulation modelling