Introduction to train path modelling

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- Purpose
- Classification of timetable models
- Train paths and blocking times
- Principles of train separation
- Different signalling systems
- Interlockings and overlaps
- Headways and buffer times
- Timetable quality
- Closing the loop
- Conclusions

Purpose

- Passenger/customer information
- Infrastructure capacity allocation
- Train operator's production plan
- Rolling stock schedule
- Drivers' and conductor's work schedule
- Traffic control
- Performance assessment

T̃U Delft

Classification of timetable models

- ❖ **scope**
  - line by line
  - network
- ❖ **kind**
  - deterministic/periodic
  - stochastic/non-periodic
- ❖ **scale**
  - macroscopic
  - microscopic
- ❖ **resilience**
  - stable/feasible
  - robust/resilient

Macroscopic

| stable | robust |

Deterministic   Stochastic

| feasible | resilient |

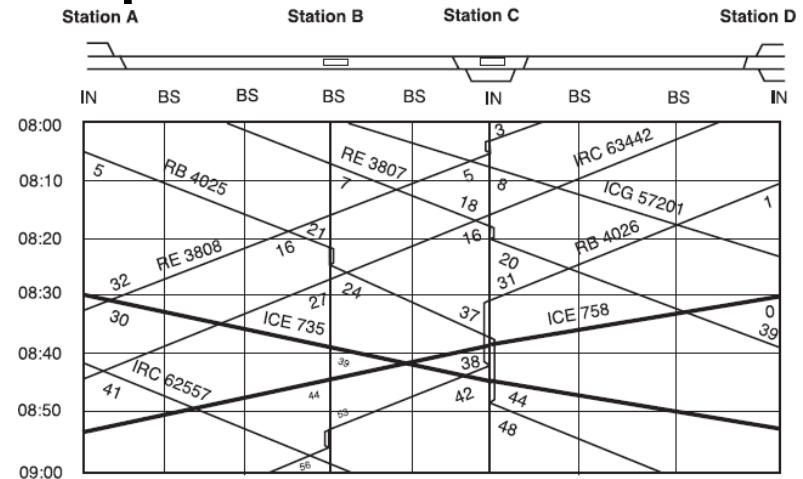Microscopic
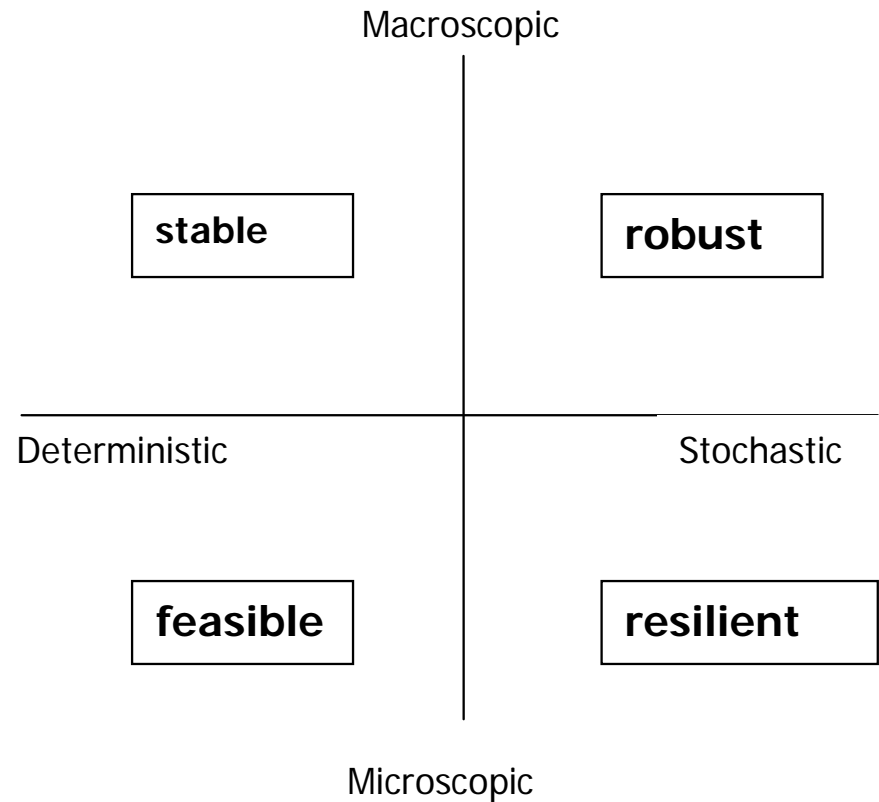
Timetable modelling – classification by scope

A. Line by line
(stepwise design)
Input: links, stations, design speed, transport demand, train capacity
Output:
- non-periodic timetable or
- periodic (clockface) timetable
- best alternative (local optimum?)
- symmetric periodic timetable
- coordination of arrival, departure and transfer times between lines

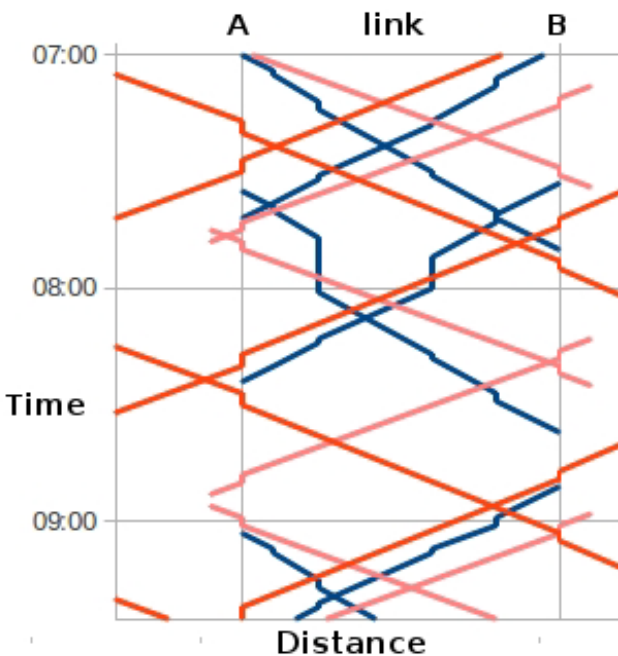B. Network (combinatorial)

Timetable modelling

A. Line by line (classic engineering approach)
- **Infrastructure, stations and distances given**
- Max. train <u>speed</u> derived from max. track design speed
- Train <u>capacity</u> given/based on transport volume forecast
- <u>Regularity</u> of passenger train intervals
- (Non-)periodic freight train intervals
- Deterministic variables only
- Minimum headway times based on rules of thumb
- Synchronization of arrival, departure and transfer connection times between lines at stations

$\Rightarrow$ Main disadvantage: difficult coordination between lines at nodes and between travel directions of single track lines
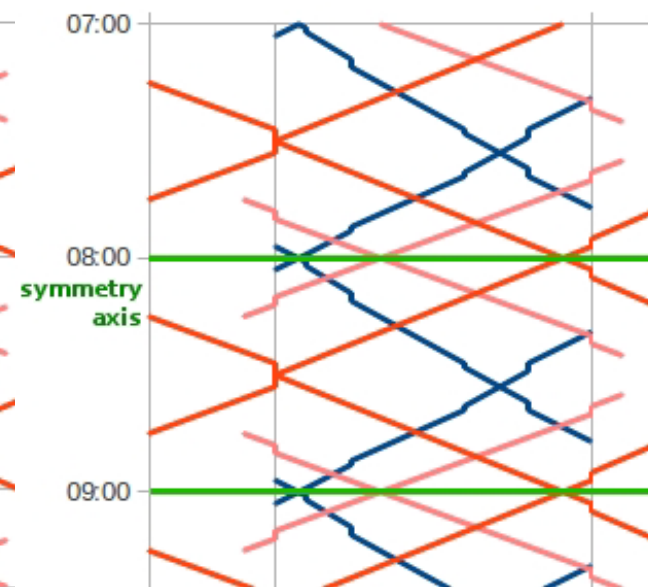
Timetable modelling – classification by kind

Non-periodic trips
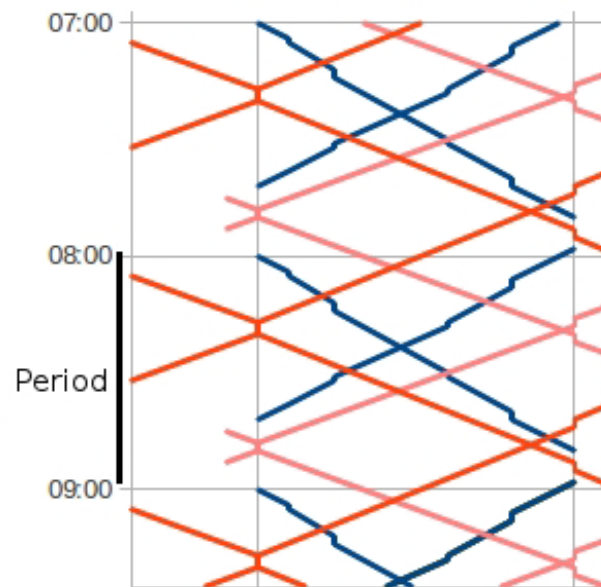
Regular (periodic) trips

Symmetric periodic timetable
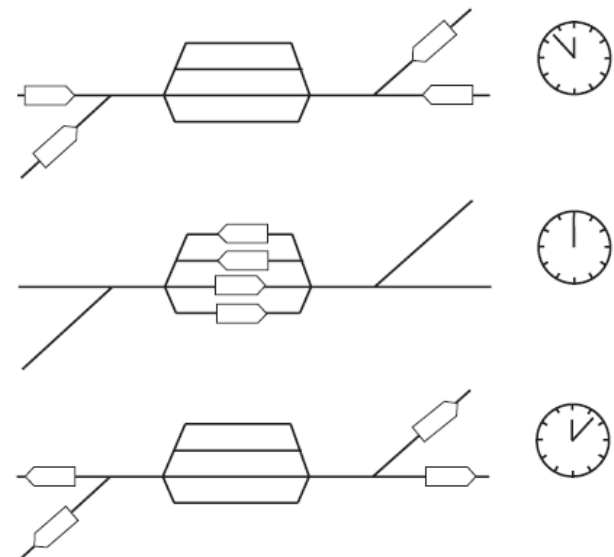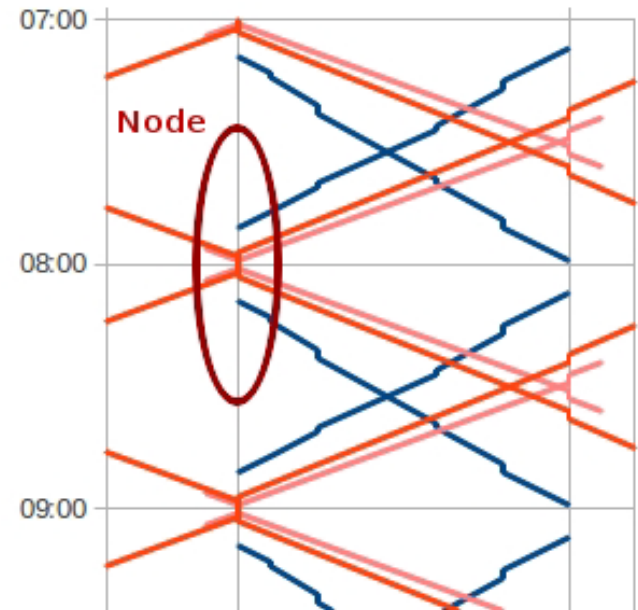
Timetable modelling

B. <u>Integrated periodic network (combinatorial approach)</u>

Input: nodes, period, frequency, min. headway

- Decomposition of network

Output:

- Running & dwell times (speed)
- Intermediate stations
- Regular periodic timetable
- Global optimum
- Integrated periodic timetable

Timetable modelling

B. Integrated periodic (clockface) timetable

1. Selection of network nodes
2. Determination/optimization of line network
   (weighted minimum travel time, waiting/transfer times and trains)
3. Choice of timetable period (synchronized arrival/departure times)
4. Determination of line frequencies
5. Estimation of compatible running times **per link**
6. Estimation of dwell and turnaround times
7. Determination of intermediate stations
8. Estimation of arrival, departure and headway times

$\Rightarrow$ Main advantage: minimum waiting and transfer times

Disadvantages: rigidity of transport supply and of scheduled running times between nodes, more platform tracks needed at nodes
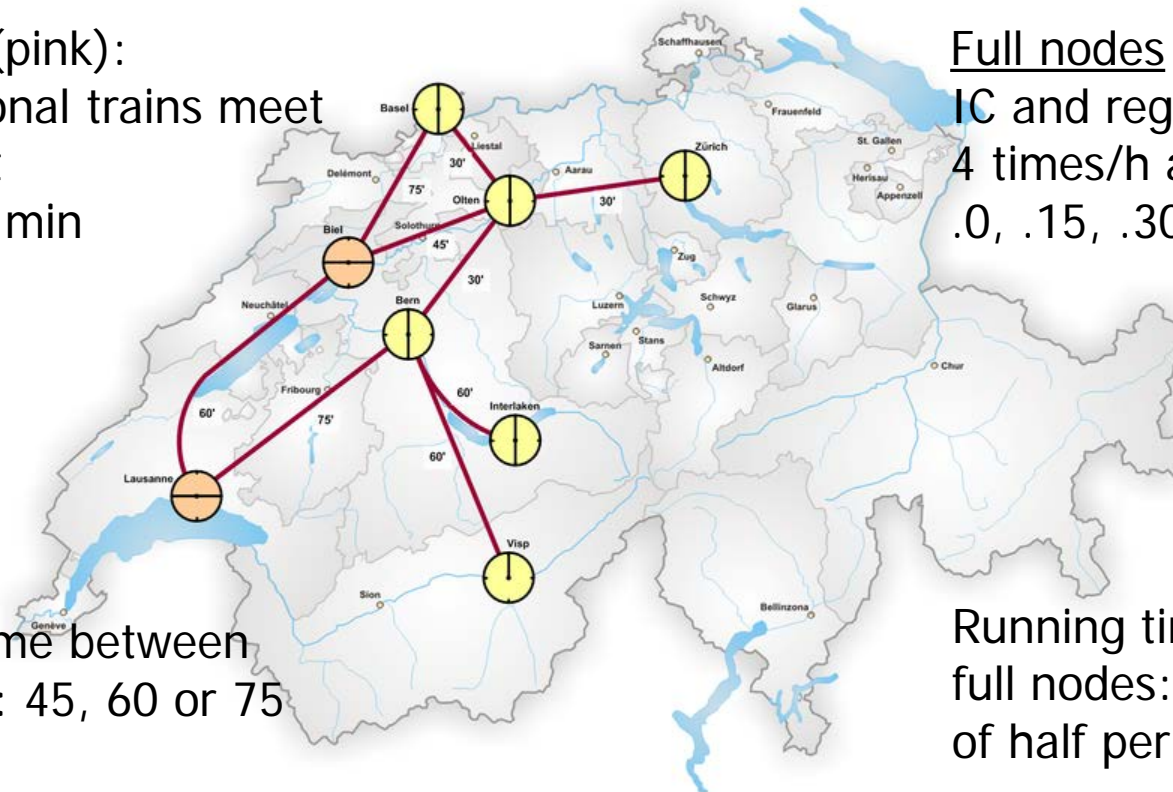
Example: Integrated periodic network timetable Swiss Railways

Half nodes (pink):
IC and regional trains meet
2 times/h at
.15 and .45 min

<u>Full nodes</u> (yellow):
IC and regional trains meet
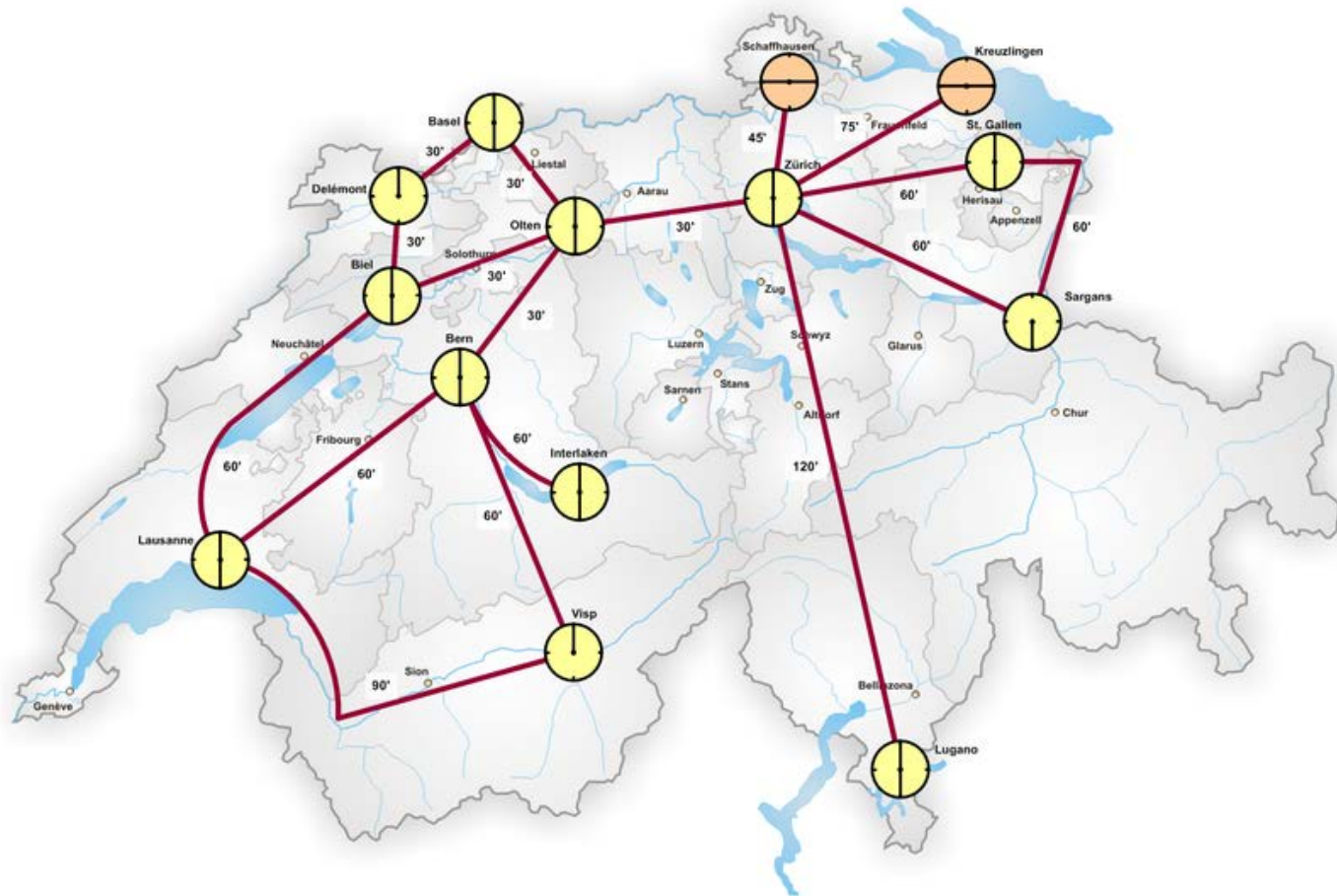4 times/h at
.0, .15, .30, .45 minutes

Running time between half nodes: 45, 60 or 75 minutes

Running time between full nodes: integer multiple of half period (30 minutes)

Timetable period: 60 minutes (integer multiple of running time between full nodes!

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Future integrated periodic timetable Swiss Railways

TUDelft

Fundamental characteristics of integrated periodic network timetables

1. Symmetry of all train paths (equal travel times) between nodes in both travel directions
2. Travel time* between the nodes must equal an integer multiple of half the timetable period
3. Sum of travel times around a circle of nodes must equal integer multiple of timetable period

*Travel time between two nodes consists of
(a) scheduled running time including supplement, intermediate stop times and timetable margins
(b) waiting times at transfer nodes on top of minimum transfer times
(c) transfer times at nodes
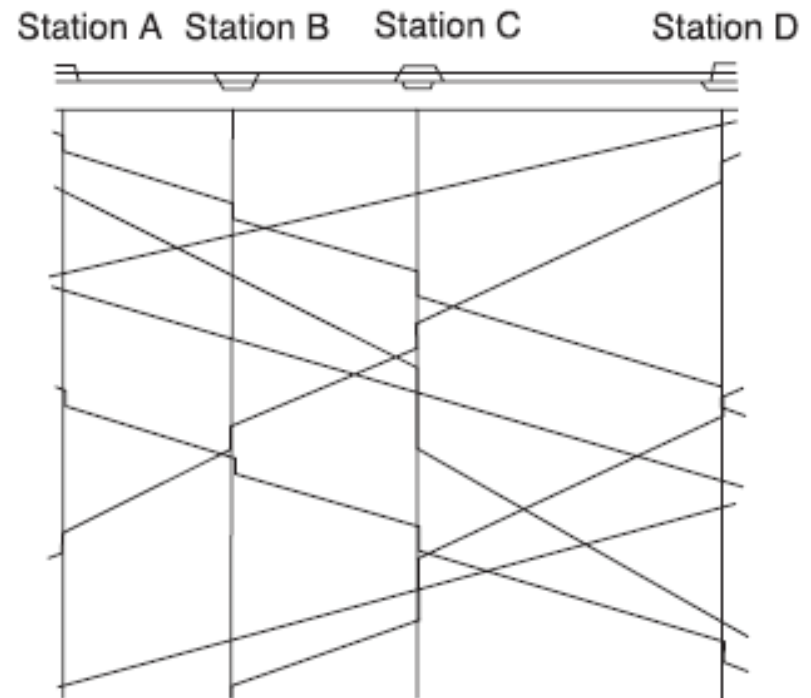(d) dwell time for boarding and alighting at each node
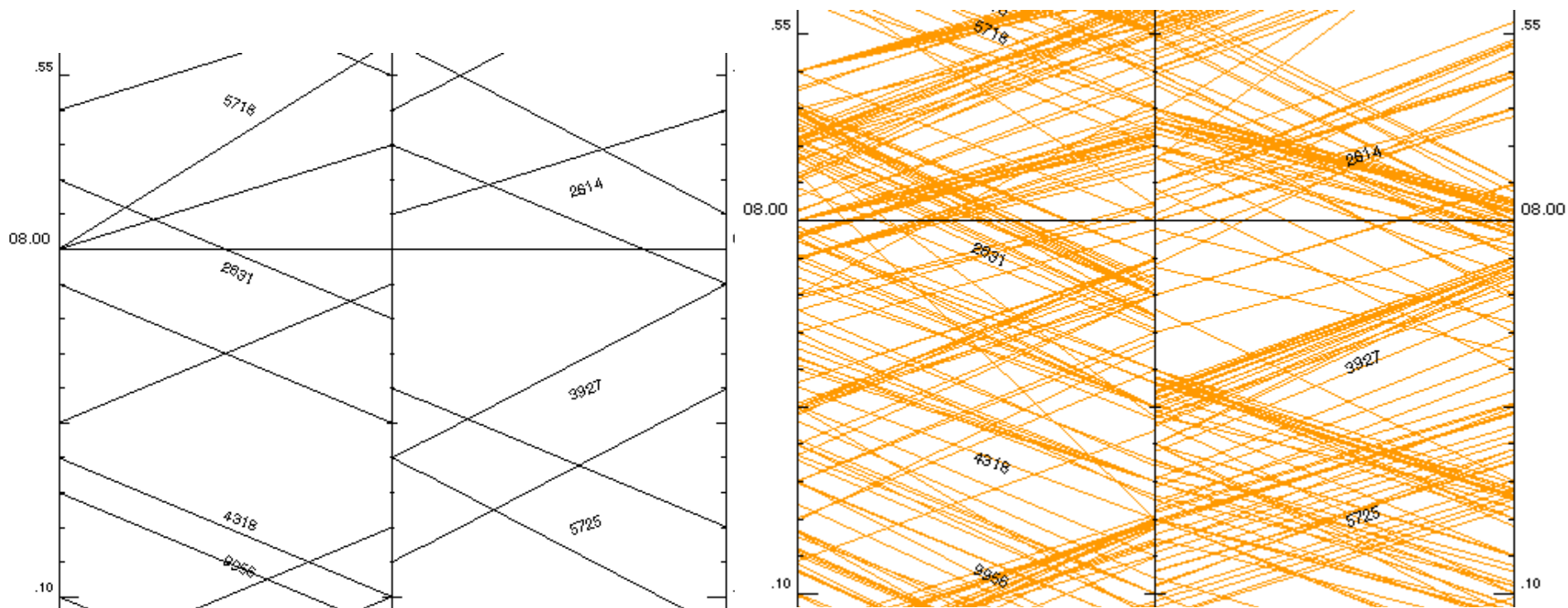
Modelling train paths

A. <u>Macroscopic</u>
   Linear strings between arrival and departure times at stations

Shortcomings:
- impact of train length neglected
- signalling constraints considered only by means of standard minimum headway times [min] depending on train order
- buffer times unknown

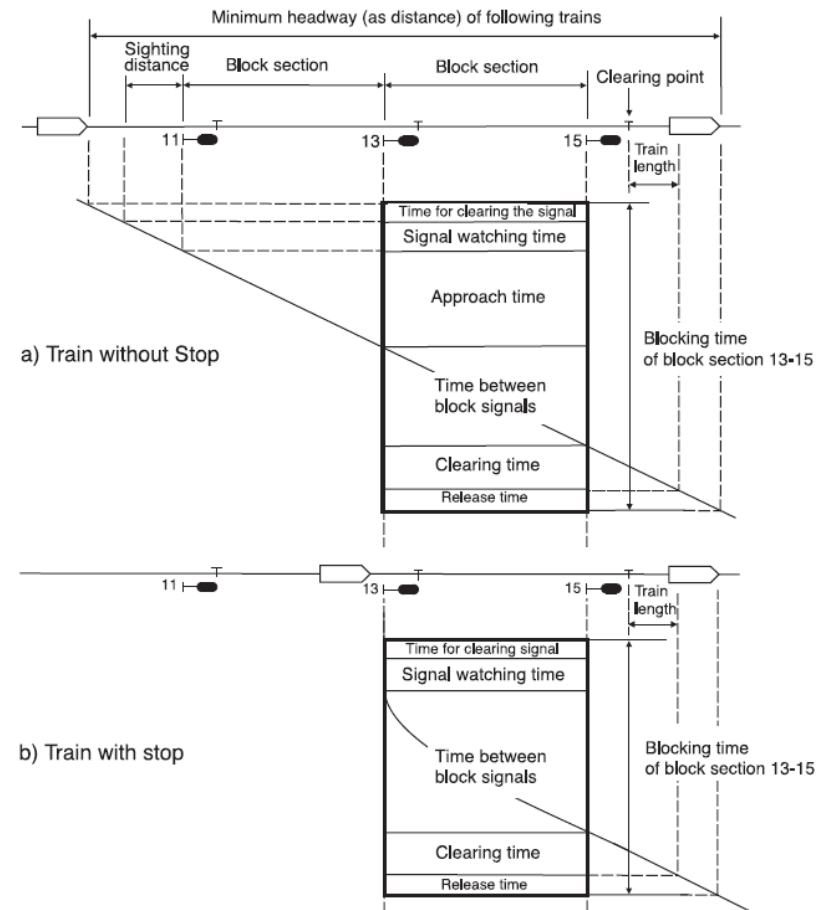# Comparison between scheduled and realized train paths
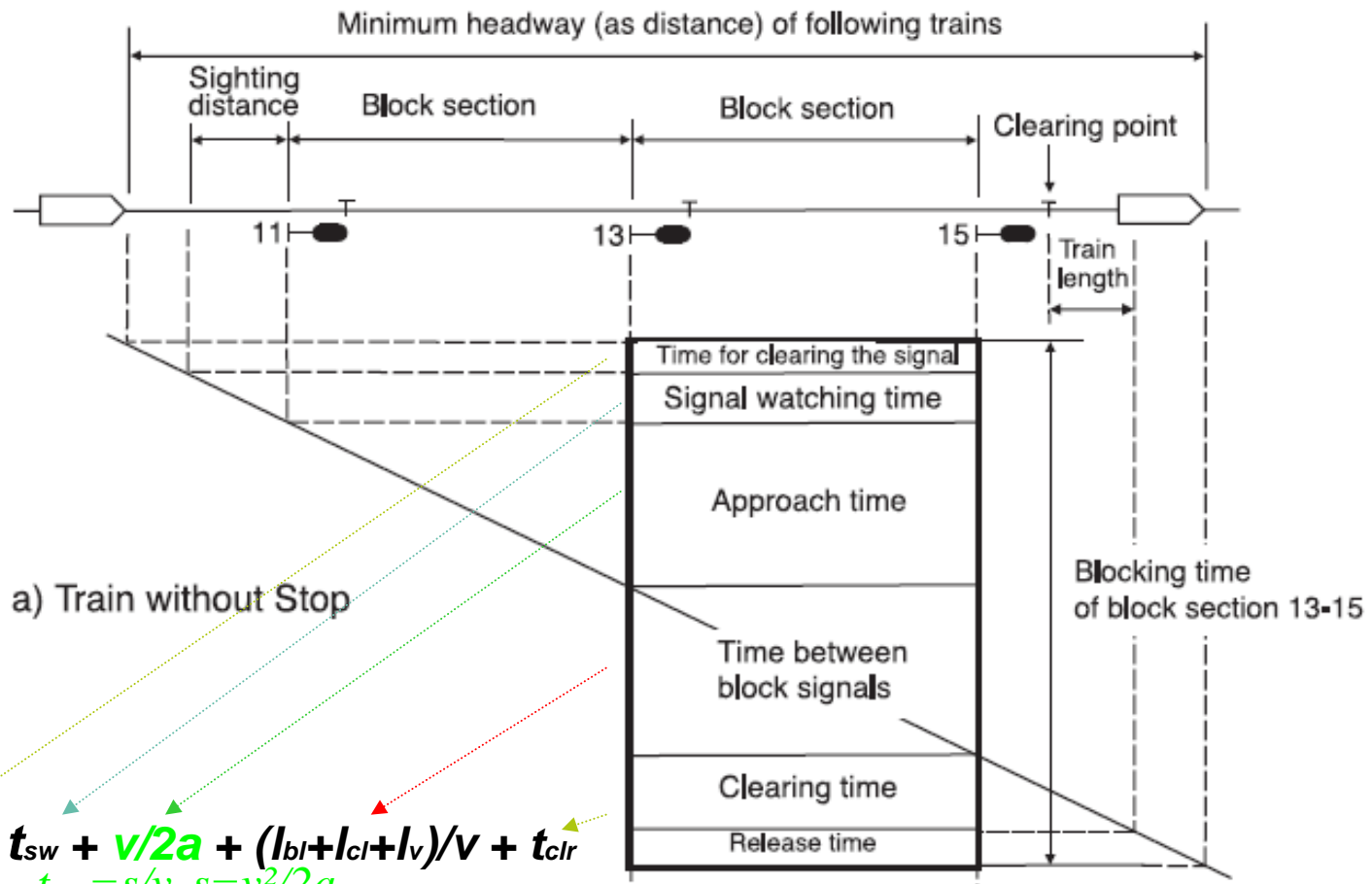
Modelling train paths

B. <u>Microscopic</u>
(Non-)linear strings between arrival and departure times enriched by
- signal clearing time
- signal watching time
- approach time
- passing times of train head at block signals (track occupation time)
- release time of train tail at insulation joints and line markers

$\Rightarrow$ **Blocking time**

Minimum headway (as distance) of following trains

Sighting distance — Block section — Block section — Clearing point

11   13   15   Train length

Time for clearing the signal
Signal watching time
Approach time
a) Train without Stop
Time between block signals
Clearing time
Release time
Blocking time of block section 13-15

11   13   15   Train length
Time for clearing signal
Signal watching time
b) Train with stop
Time between block signals
Clearing time
Release time
Blocking time of block section 13-15

Blocking time estimation through running train

a) Train without Stop

$t_{bl} = t_{cls} + t_{sw} + v/2a + (l_{bl}+l_{cl}+l_v)/v + t_{clr}$

$t_{app}=s/v, \; s=v^2/2a$

otherwise $t_{app}=l_b /v!$

Principles of train separation

$\Rightarrow$ <u>Movement Authority (MA) for train run at safe headway distance</u>
Note: Speed restrictions at open track sections or interlocking areas
increase min. headway if block length is not reduced!

1. **Fixed block signalling**
   MA transmitted from track to
   train at discrete points
- signal block length $\geq$ absolute
  braking distance
- signal block allocated
  exclusively to one train at time
- conflict-free timetable:
  blocking times of following
 trains must not overlap!
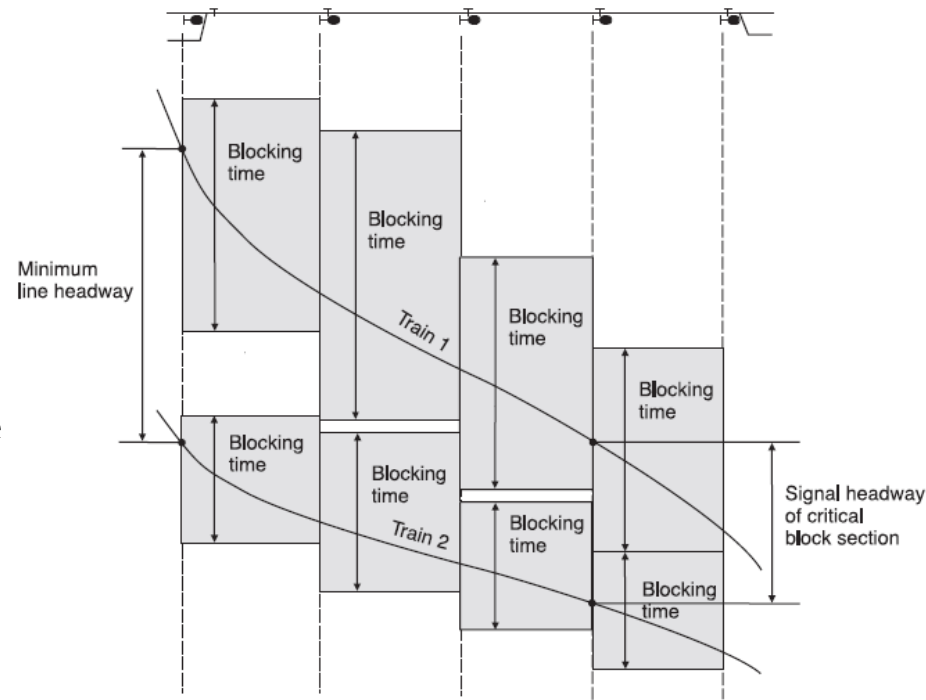
Modelling cab signalling

2. Cab signalling (ETCS L2)

MA updated when train passes at every track section border

- minimum headway distance depending on actual train speed and number of track sections (≥ braking distance)
- minimum headway time significantly reduced due to better fit of disaggregated blocking time staircases

a) Train governed by cab signals

b) Train without working cab signals
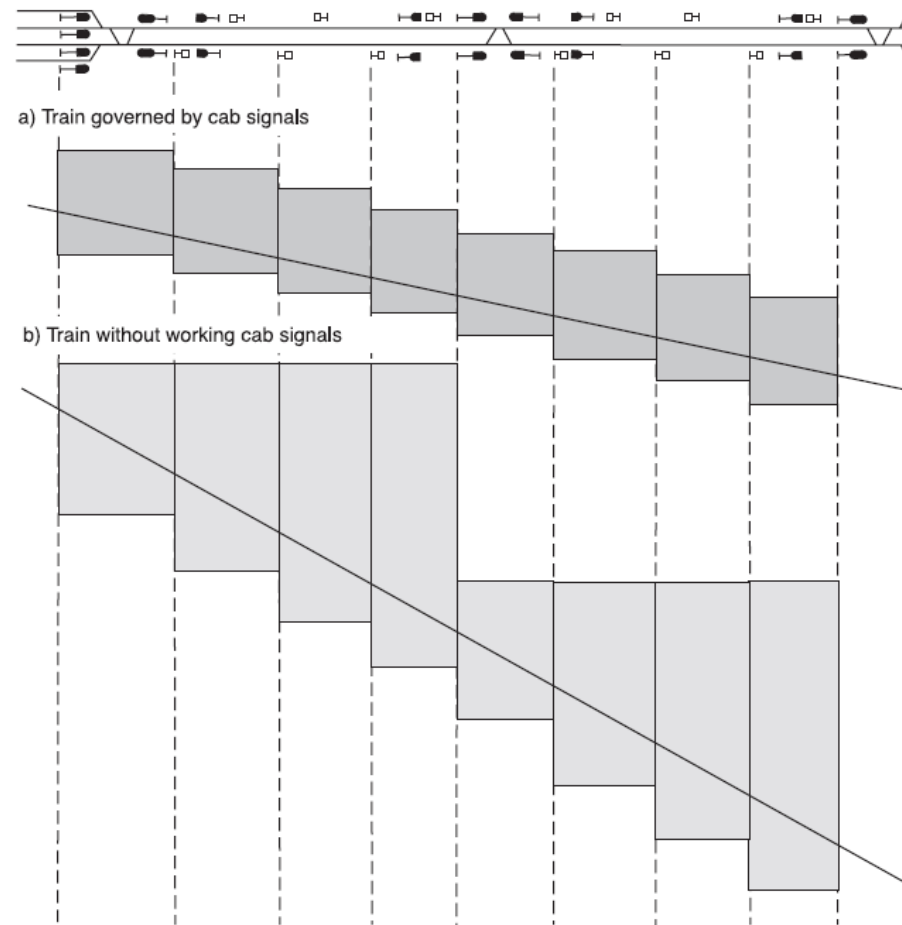
Modelling Moving Block

3. Moving block (ETCS L3)
MA updated at any time depending only from safe distance to next point of danger (speed limit, distance to tai of preceding train

- blocking time steps very short
- nearly continuous line of start and end of blocking time graph on oper track
- significant reduction of minimum headway on open track sections especially when running at reduced speed
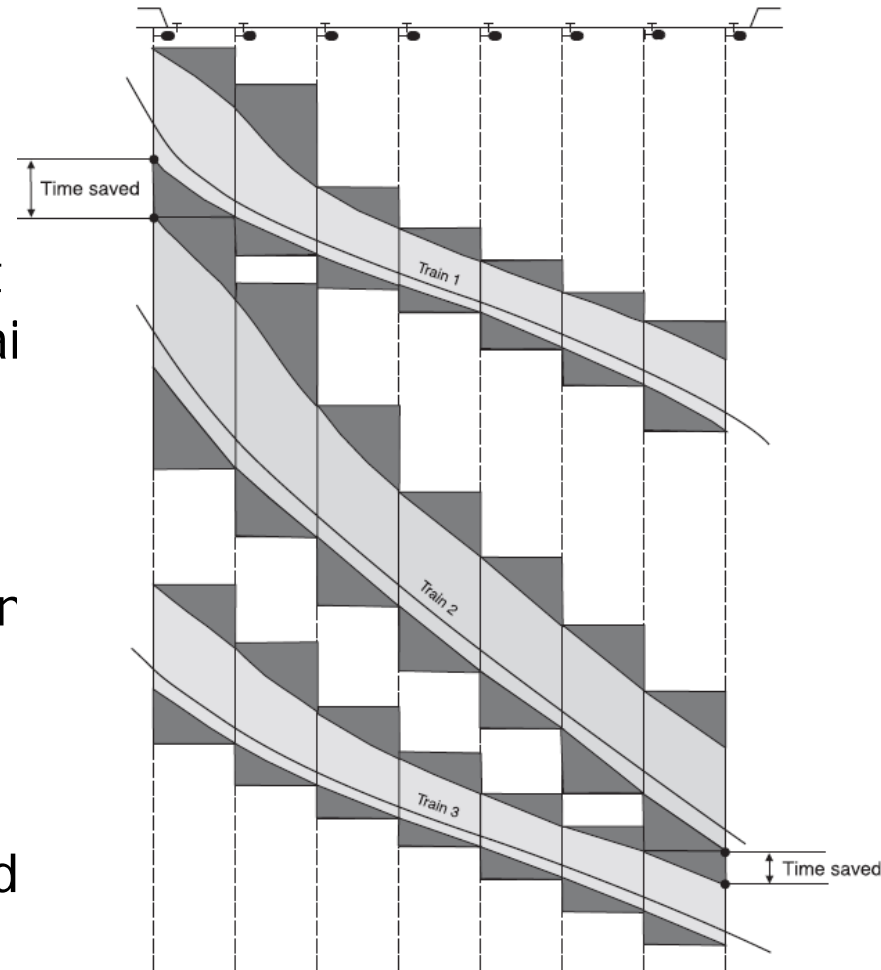
Modelling of Moving Block at track discontinuities

⇒ blocking times at route &
speed discontinuities increase
rapidly!

⇒ minimum headway time in
stations depend mainly on dwell
times and route conflicts

branching-off point
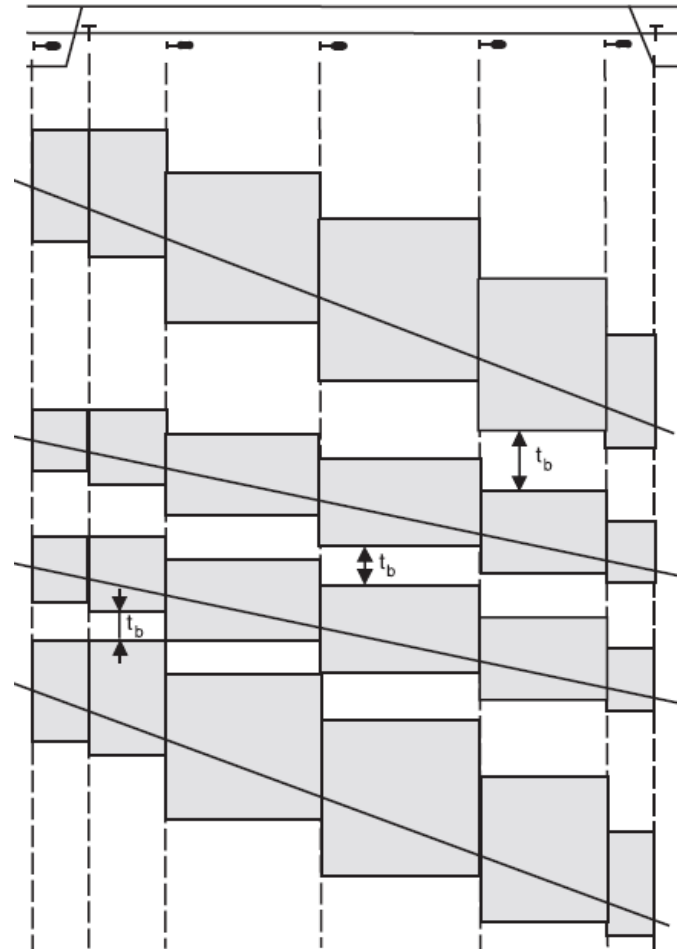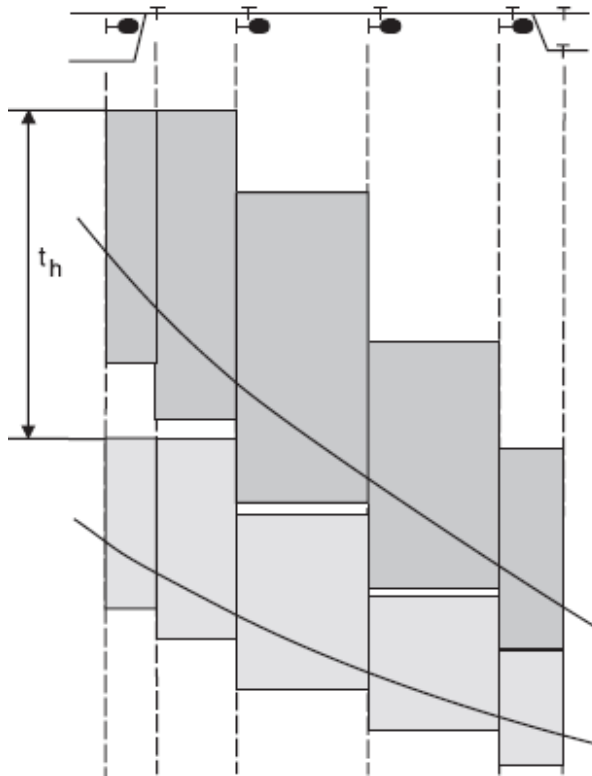
catenary
disconnector

TUDelft
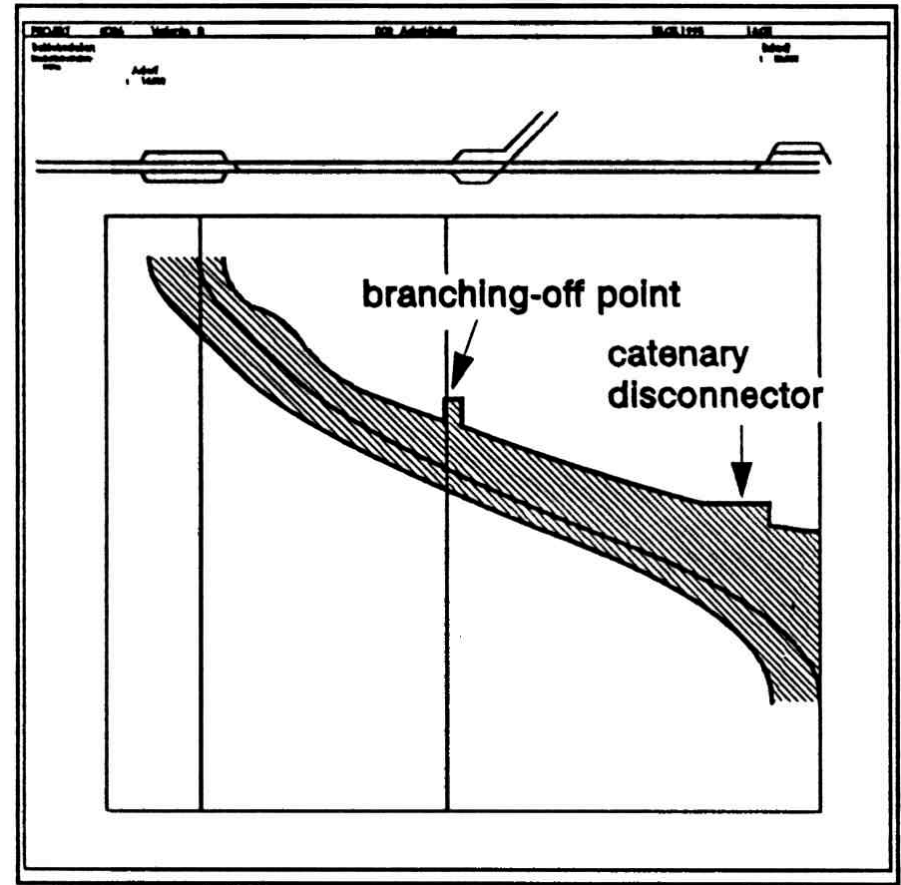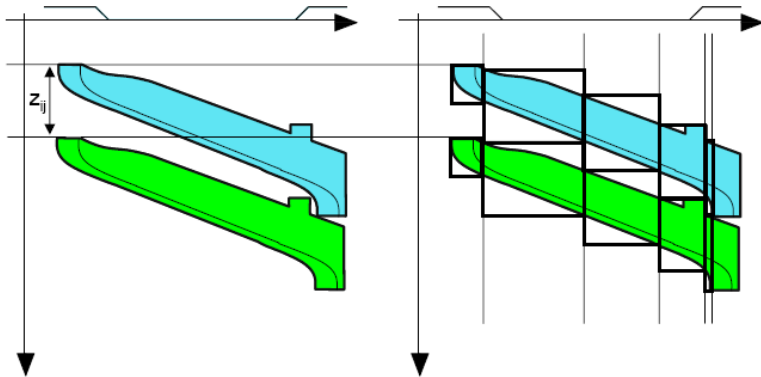
Modelling interlockings and overlaps

Blocking of route from home signal until departure signal including overlap

- sectional release of routes
- release of overlap after arrival and stop at platform
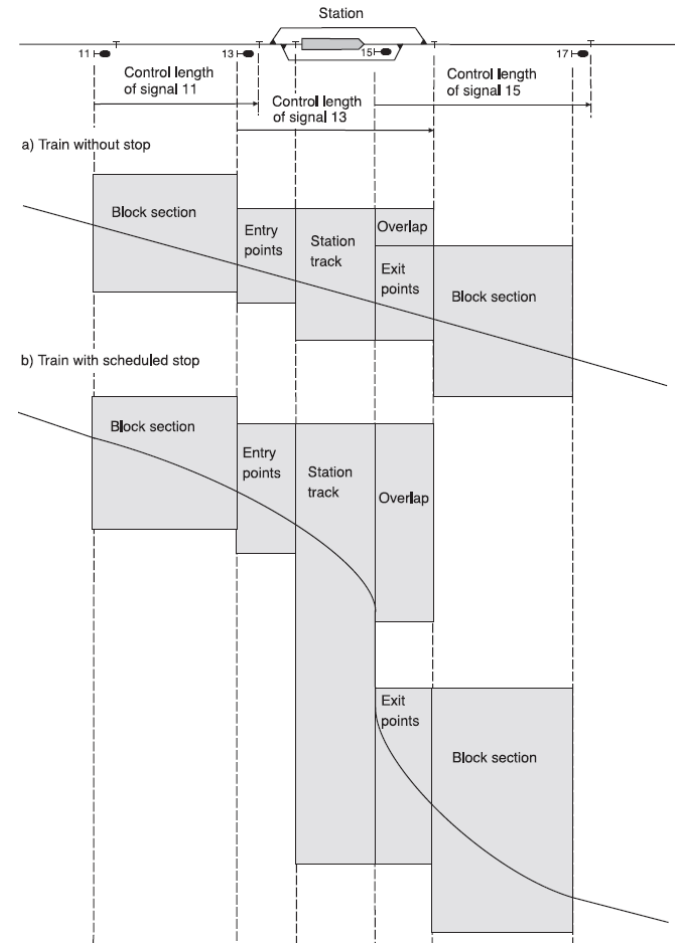
Modelling of headway and buffer times on double track line

Modelling of headway and buffer times at single track passing loop

Blocking of route and platform track until arrival of 1st train at departure signal

- sectional route release of 1st train after clearing route node
- nearly simultaneous arrival of 2nd train if loop length ≥ braking distance
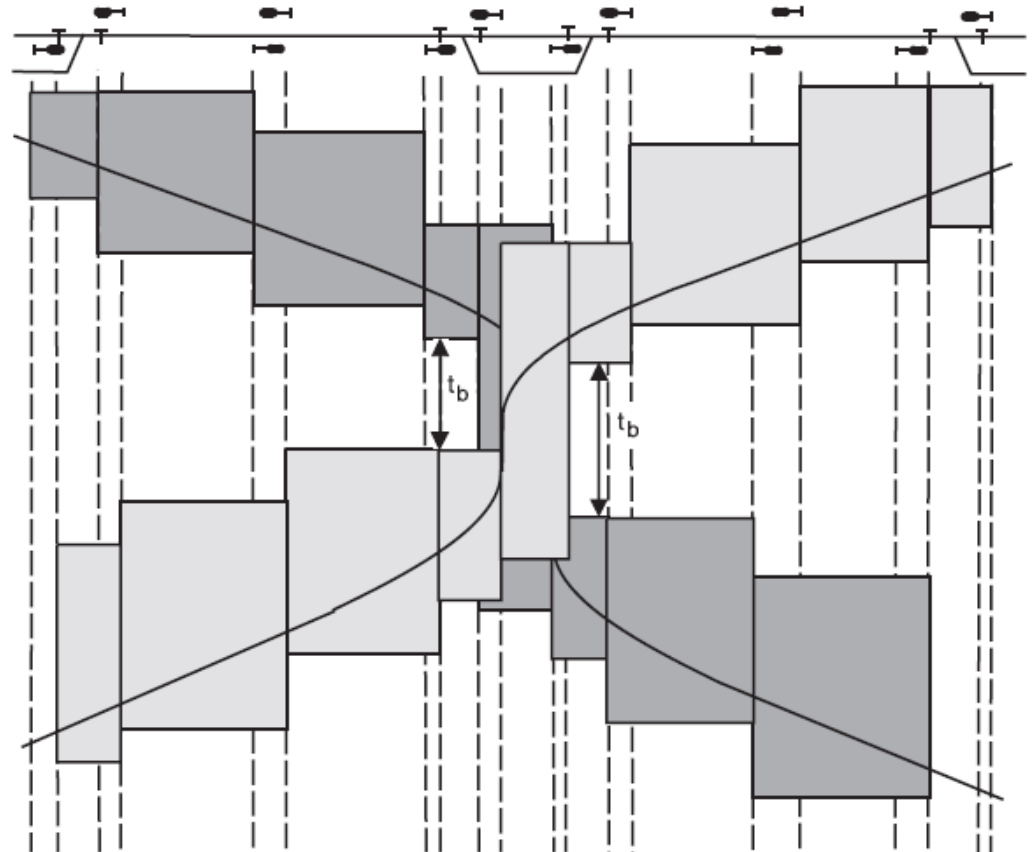
Timetable quality

Requirements	Indicators
• consistency	- running time estimation true
	- train paths conflict-free!
• reliability	- punctual, scheduled speed
• feasibility	- sufficient margins such that regular
• stability	delays can fade-out
• robustness	- resistent to stochastic perturbations
• resilience	
• efficiency	- high productivity (ratio of running time/circulation time, low share of dwell and turnaround times)

➢**Model = Operations!**

Closing the loop between timetabling and operation

Planning

Operation

Traffic

Timetabling

Monitoring

Travel

Rescheduling

Customers
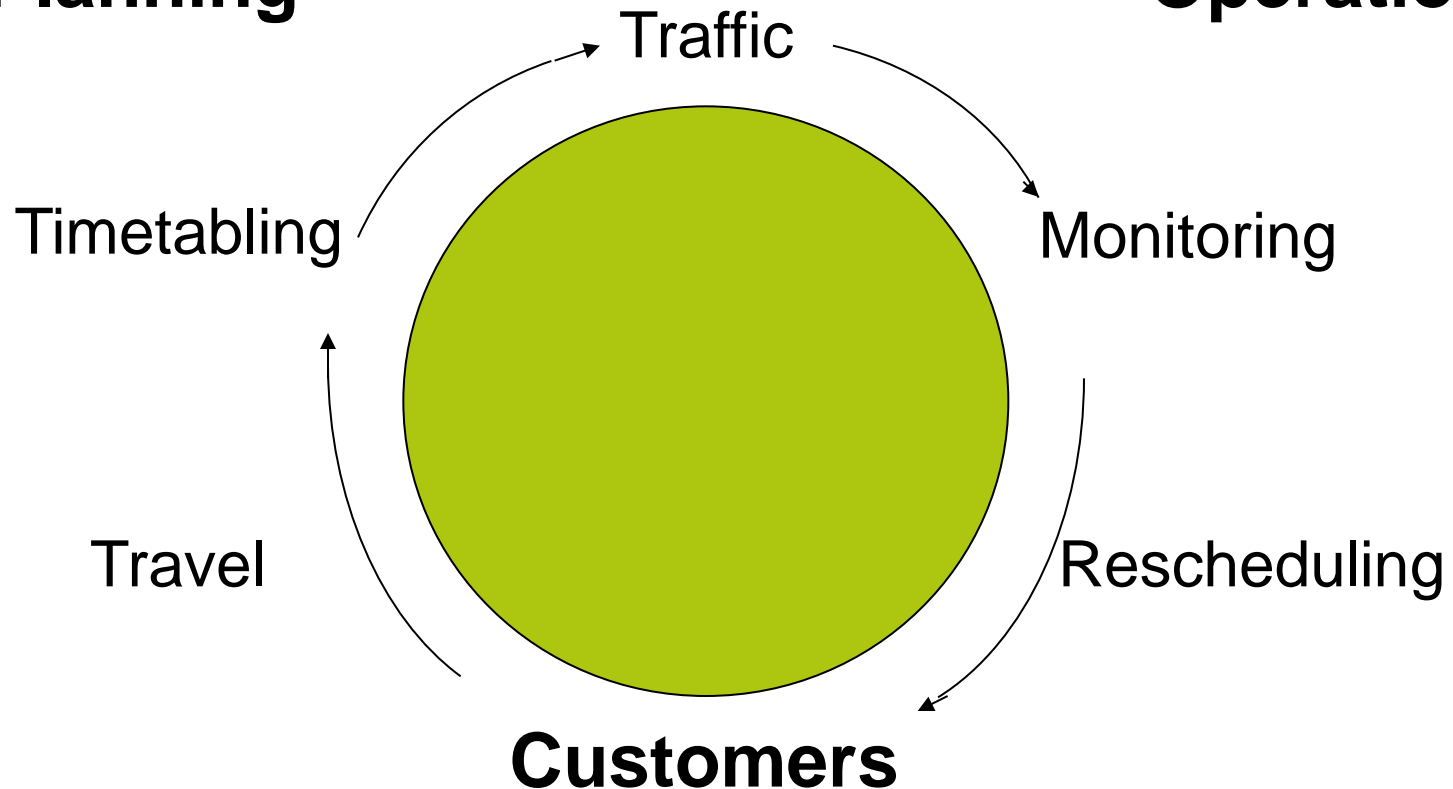
Conclusions

- Conventional timetables are designed line by line with predetermined route speed following infrastructure design; timetables are constructed and synchronized stepwise.
- Periodic network timetable design is based on regular intervals of lines whose travel time between the nodes depends strongly on the period time; optimal periodic network timetables can be computed.
- Timetable quality is high when the train circulation is efficient and real train operations are reliable, punctual and robust against disturbances.
- Macroscopic models are suitable for stability and robustness analysis of large network timetables.
- Microscopic models and simulation are needed to prove the timetable feasibility and resilience of densely occupied lines and station tracks.

Literature

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- Liebchen, C. (2006), Periodic timetable optimization in public transport, PhD thesis, TU Berlin
- Liebchen, C. (2005), Fahrplanoptimierung im Personenverkehr – muss es immer ITF sein?, *Eisenbahntechnische Rundschau ETR,* 54(11), 689-702
- Lichtenegger, M. (1991), De Integrierte Taktfahrplan, *Eisenbahntechnische Rundschau ETR,* 40(3), 171-175
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