

# Capacity Estimation Principles and Methods

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27-11-2017

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  - Compression of blocking time graphs
  - Microscopic capacity estimation
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# Objectives for capacity studies

- Strategic:
    - Infrastructure planning
    - Bottleneck analysis
  - Tactical:
  - Operational:
- Dimensioning new lines & stations
  - Upgrading existing infrastructure
  - Additional tracks, switches, signals
  - Timetable alternatives
  - Capacity consumption
  - Timetable stability
  - Quality of service
  - Timetable robustness

# Capacity issues of the HSR Hong Kong – Guangzhou



- Which is the optimal stop pattern of the new HSR line?
- How many trains can be operated during peak periods?
- Which is the capacity of the new terminal stations in Hong Kong and Guangzhou respectively?
- How robust is the new timetable against disturbances and disruptions?

# Definition of Capacity

Maximum number of trains  $N$  that may be operated using a defined part of the infrastructure at the same time during a defined time period  $[1/T]$ ;  $T$ : Time period [24 h = 1440 min; 1 h = 60 min]

- **Theoretical** capacity  $C = T / \sum(t_{h\ min} + \Delta t)$

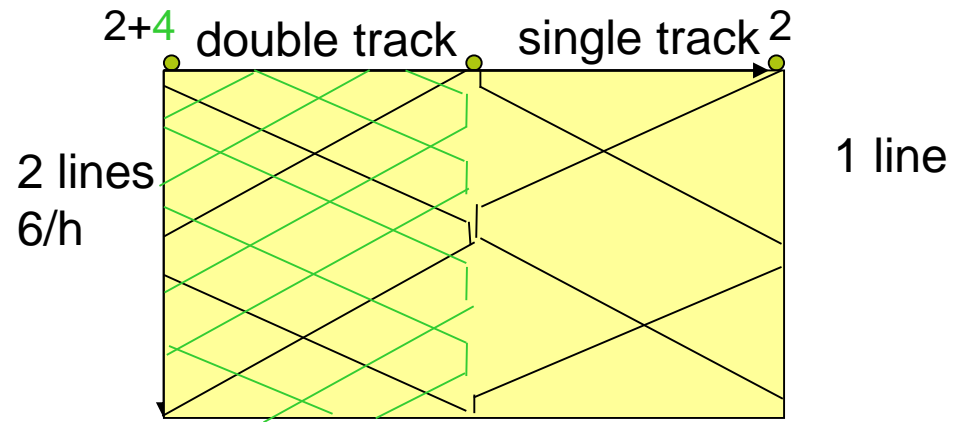
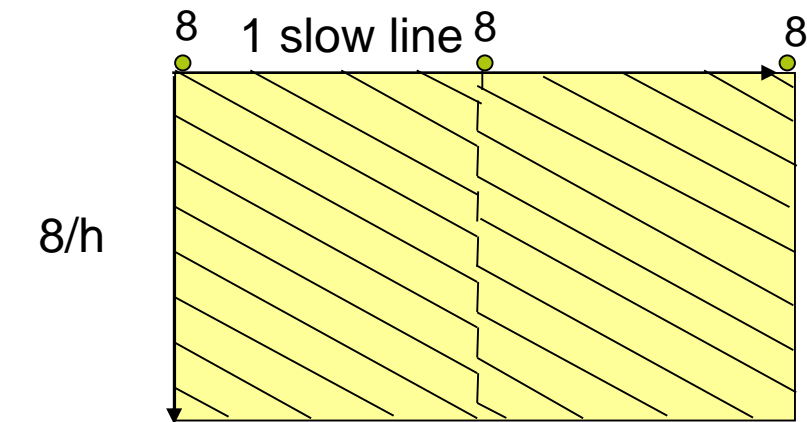
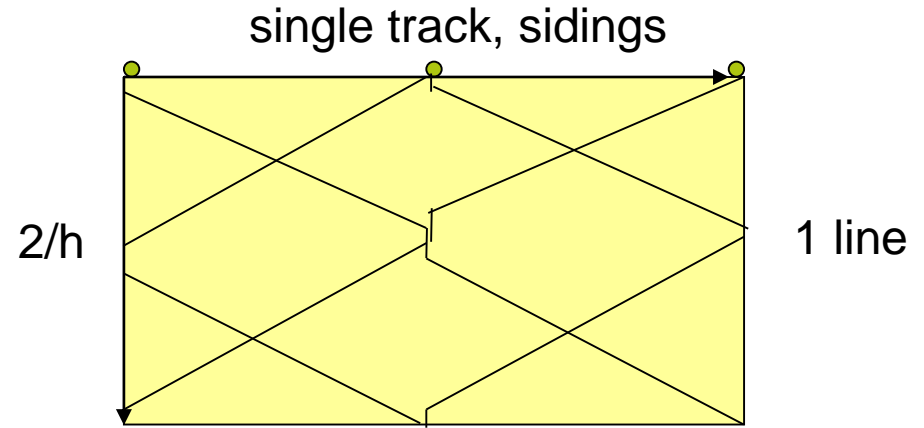
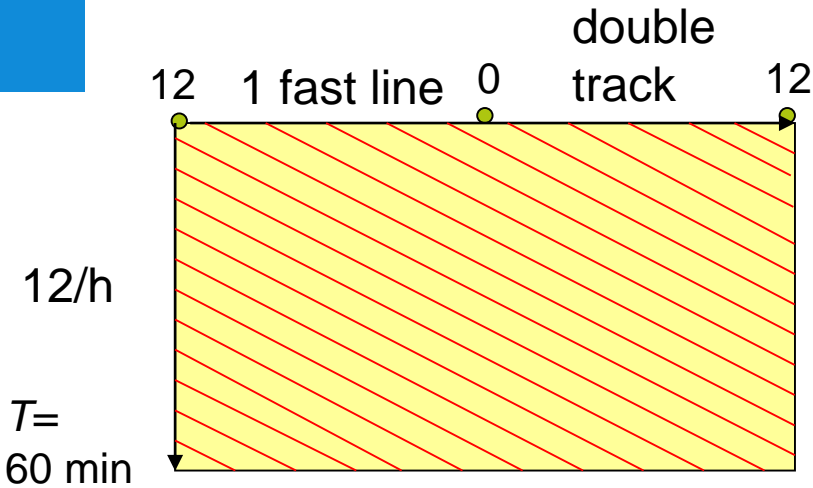
Maximum number of trains  $N_T$  at scheduled order and speed without timetable margins;  $t_{h\ min}$ : minimum headway time

$\Delta t$ : running time difference between successive trains

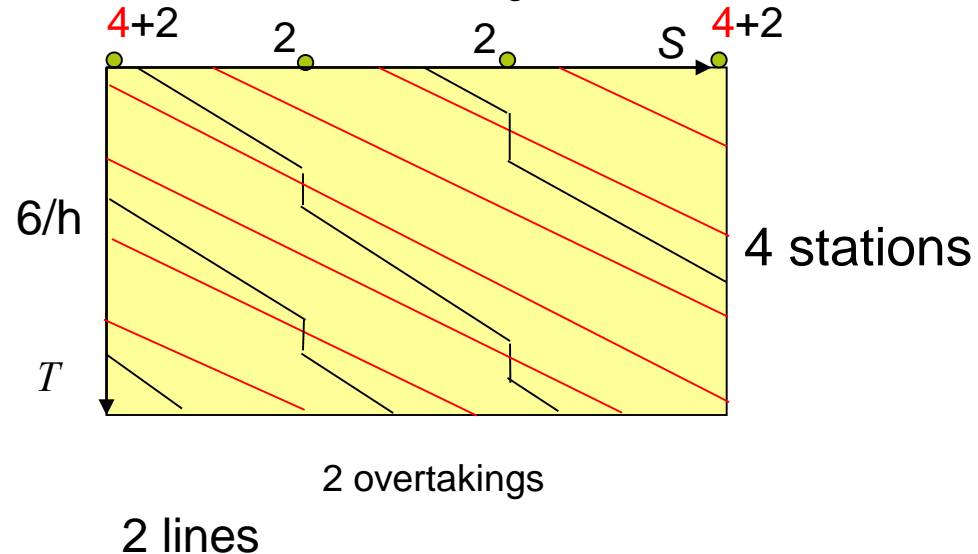
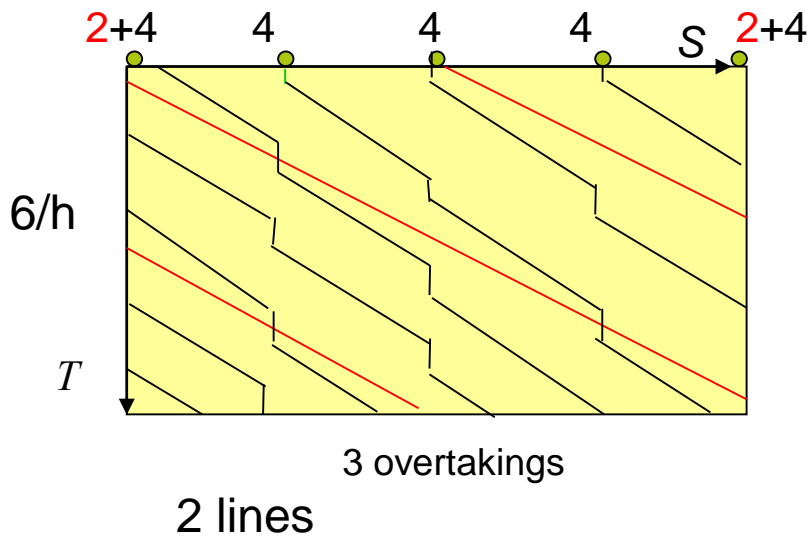
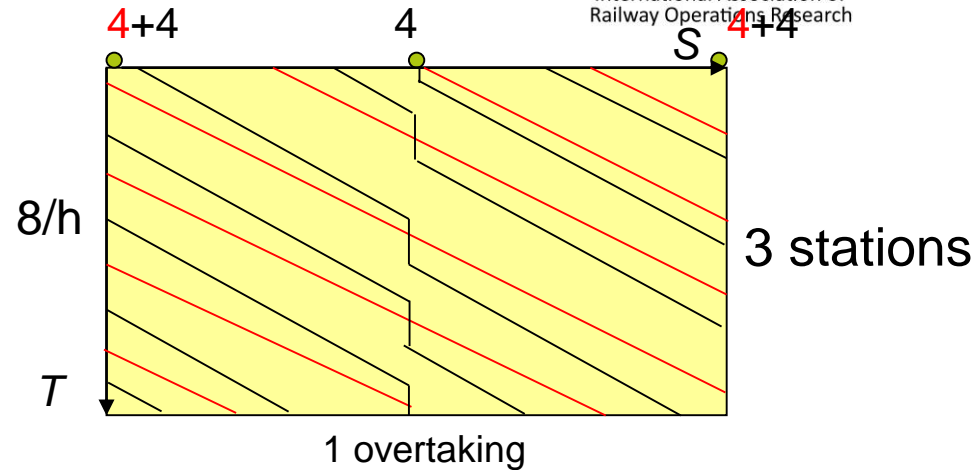
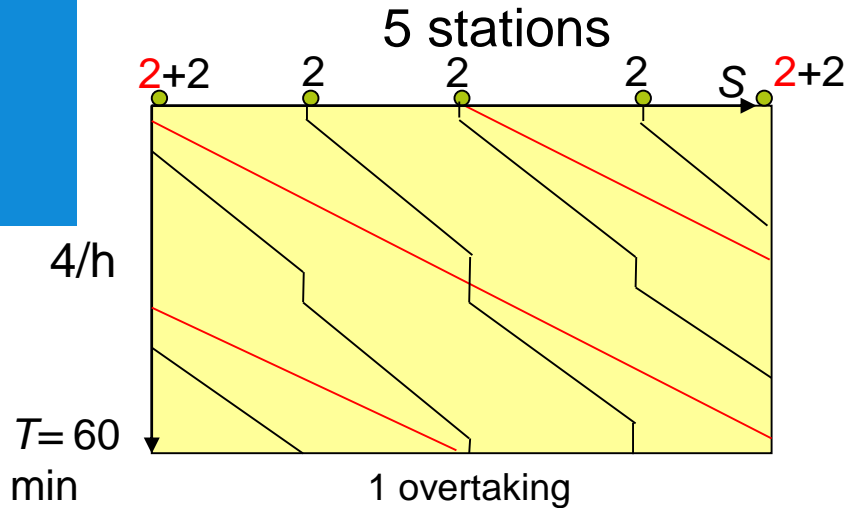
- **Practical** capacity  $C_p = T / \sum(t_{h\ min} + \Delta t + t_r + t_b + t_m)$

Maximum number of trains  $N_P$  at scheduled order and speed including running time supplements  $t_r$ , buffer times  $t_b$  and track possession time  $t_m$  for infrastructure inspection and maintenance

# Impact of speed and number of tracks on capacity



# Impact of station density, service pattern and overtakings on capacity

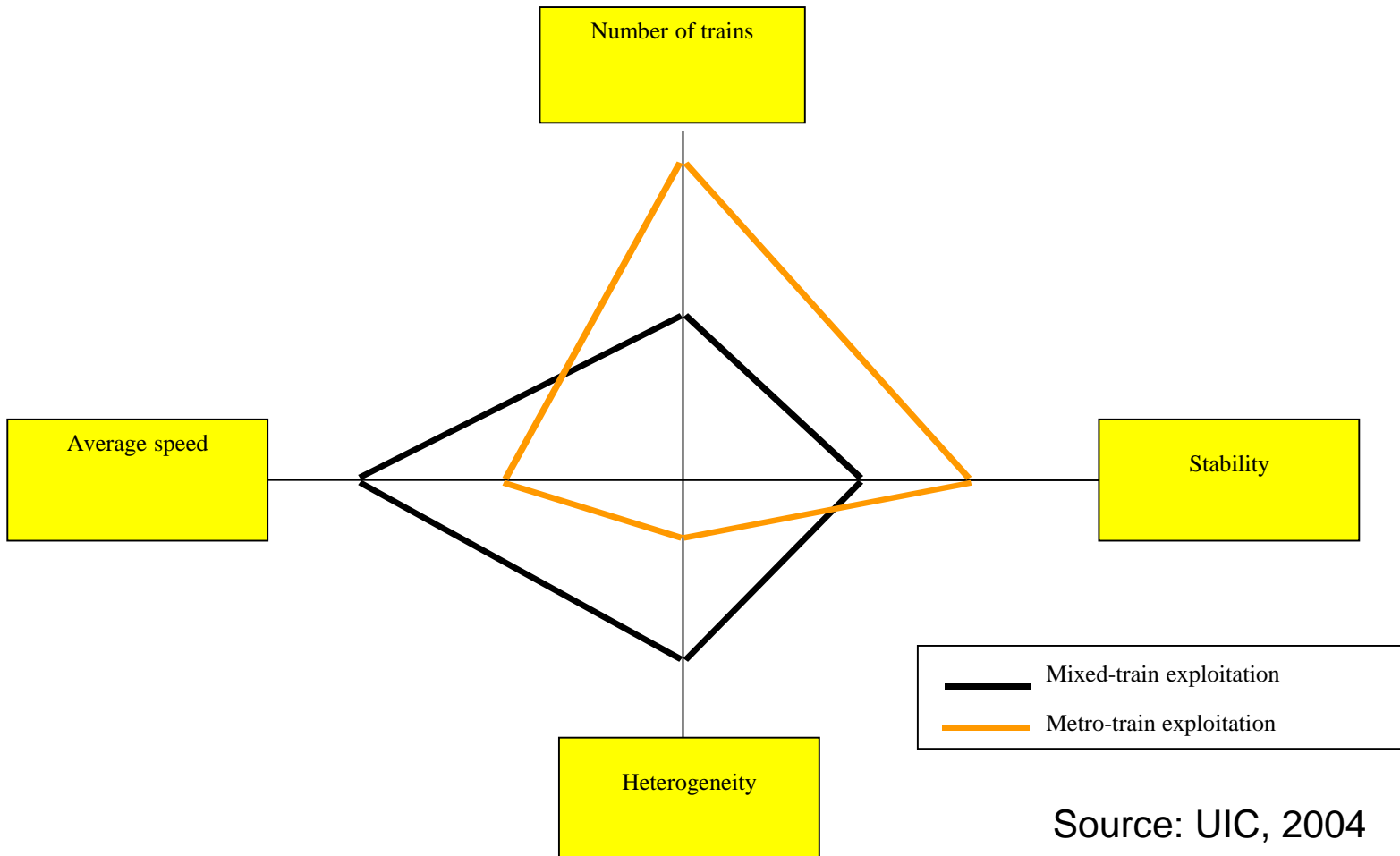


# Capacity depends on

- **Timetable**
    - Train speed and homogeneity
    - Train order
  - **Infrastructure**
    - Alignment
    - Number and length of tracks
    - Number of stations
    - Number of lines
    - Signalling & safety system
  - **Rolling stock**
  - **Weather**
  - **Human behavior**
- Travel time differences
  - Minimum headways
  - Timetable margins
  - At-grade crossings, flyovers, speed reductions, steep gradients
  - Single (bidirectional), passing loop
  - Double, merging/diverging/crossing, terminal, stabling
  - Fixed block {one-section/multiple track sections}
  - Automatic Train Protection (ATP)
  - Automatic Train Control (ATC)
  - Automatic Train Operation (ATO)
  - Moving block



# Capacity balance



Source: UIC, 2004

# Classification of timetabling and capacity estimation models



A. Stage of planning/ implementation	A.1 Strategic A.2 Tactical A.3 Operational		
B. Type of model	B.1 Deterministic B.2 Stochastic	Graphical/Simulation Analytical/Math. program	Probabilistic
C. Scope	C.1 Dedicated line(s) C.2 Stations C.3 Networks	single track	multiple tracks
D. Scale/discretization	D.1 Macroscopic D.2 Microscopic	km cm	minutes seconds

# Network disaggregation into line sections

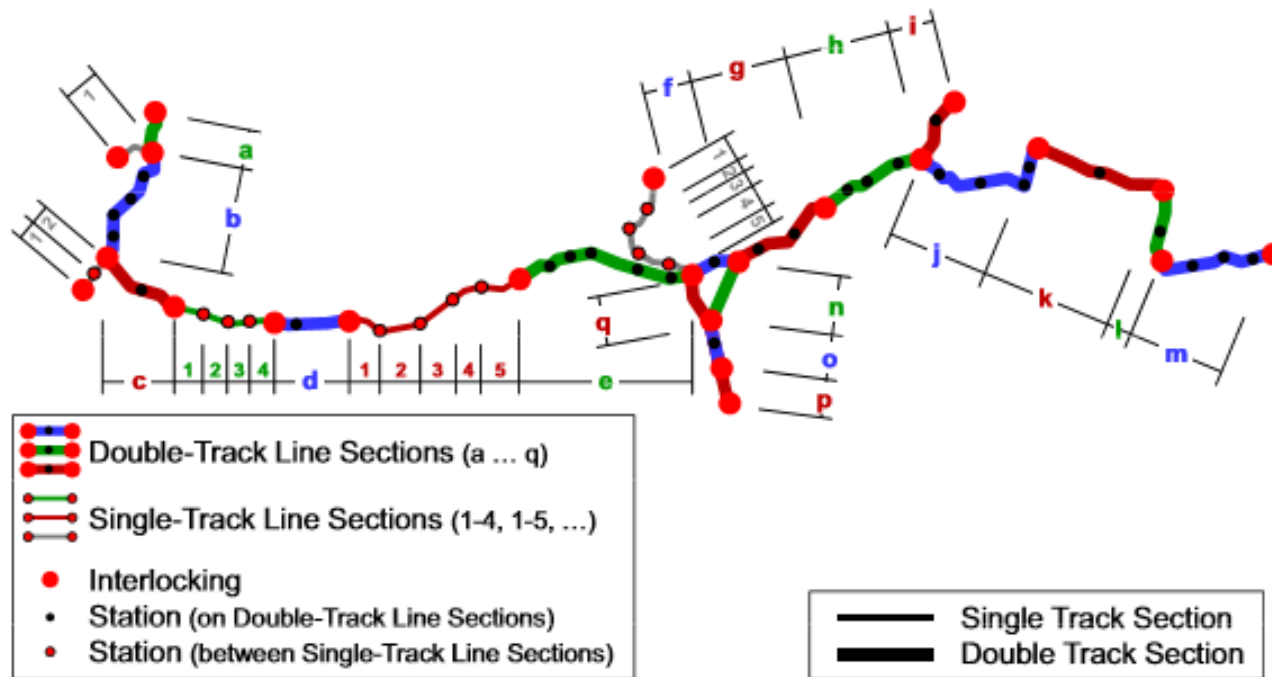
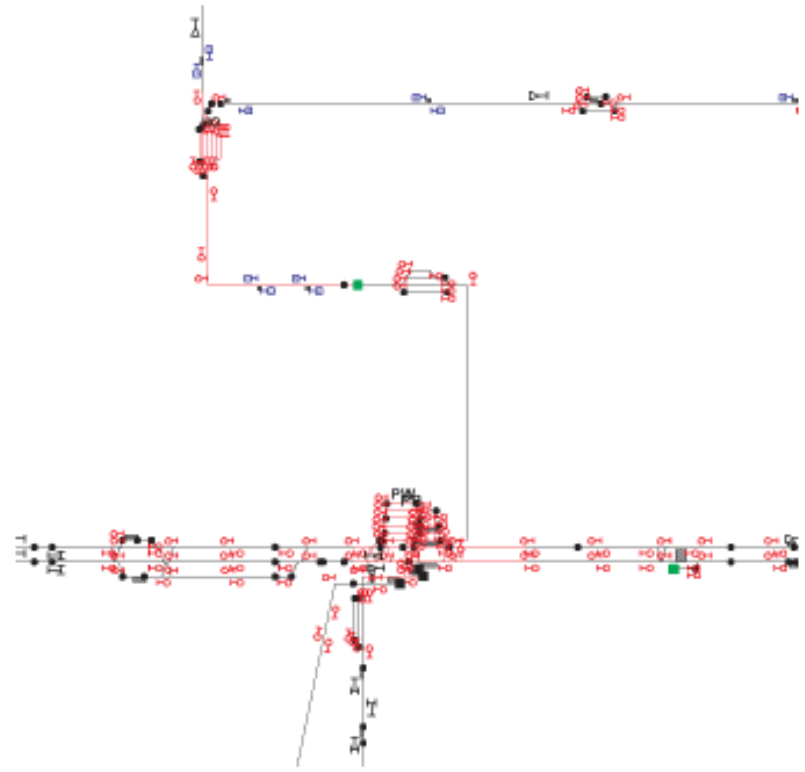
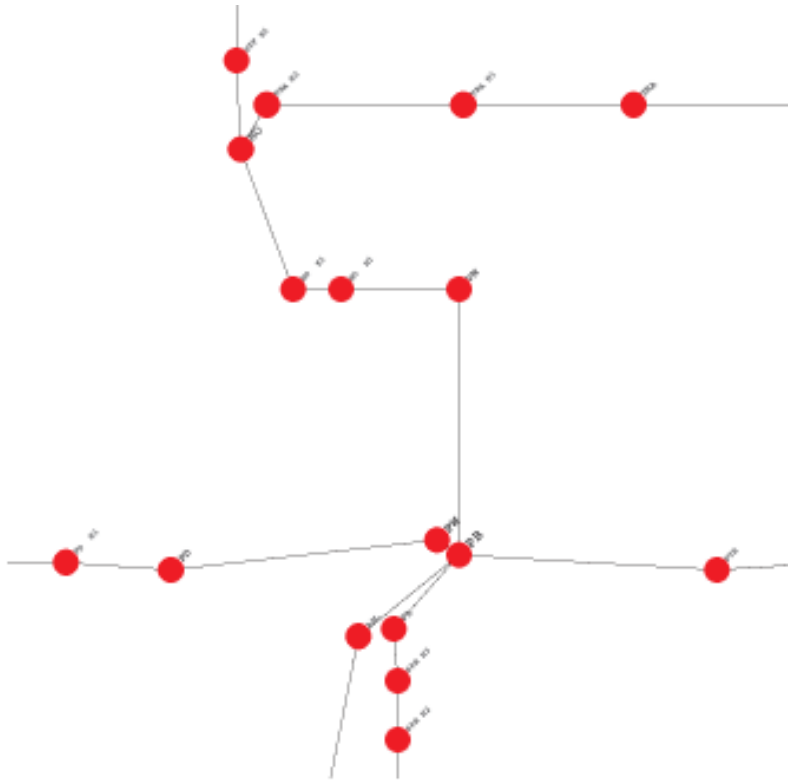


Fig. 12 - Covering a network with line sections

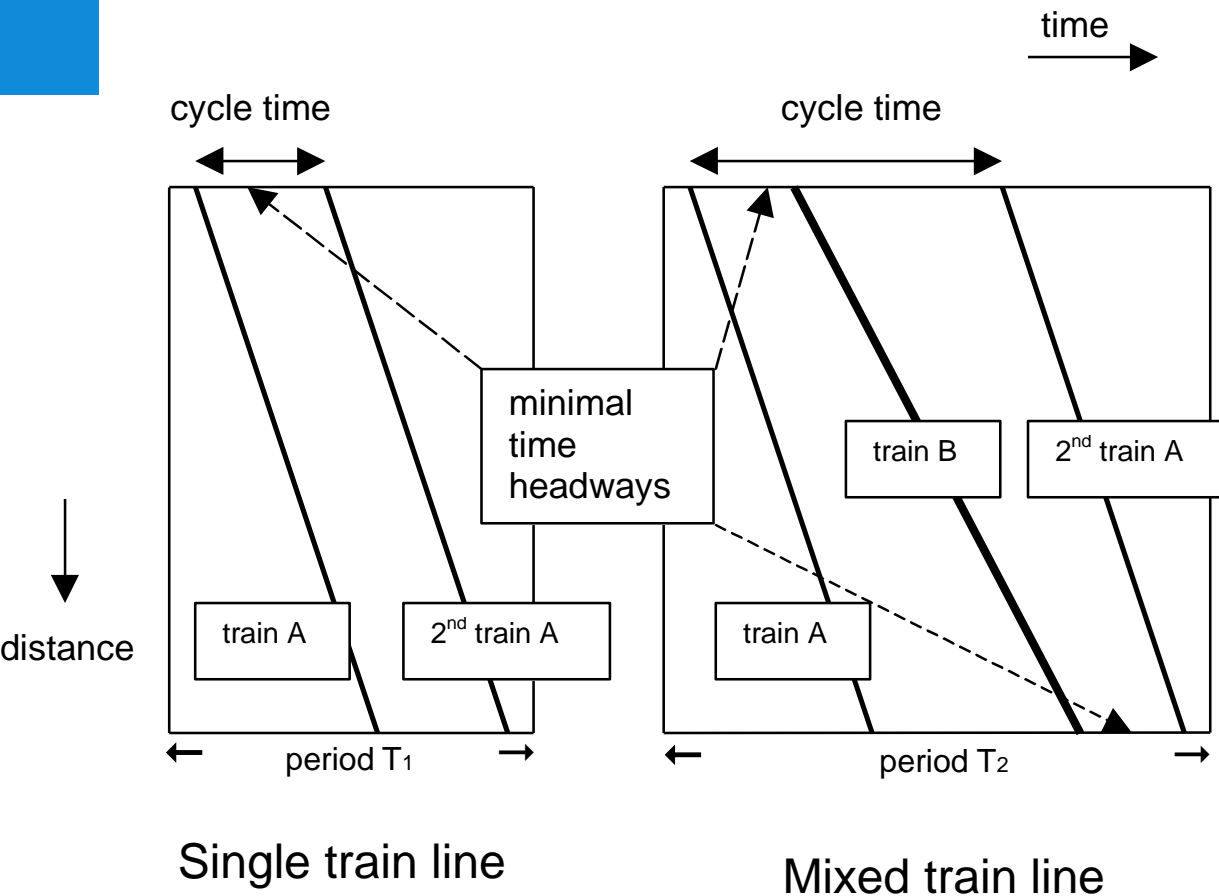
Source: UIC (2013)

# Network modelling: Macroscopic

# Microscopic



# Macroscopic capacity estimation



Cycle time:  $t_c$  [min]

Number of cycles/period:

$$n = \lfloor T / t_c \rfloor$$

Time headway:  $t_h$  [min]

Number of trains/period:  $N$

Minimum time headway:  $t_{hmin}$

Mean min. time headway:

$$\bar{t}_h = f(t_{hmin}, \Delta t, N)$$

**Track occupation:**

$$\rho = n \cdot t_c / T [-]$$

**Capacity:**

$$C = T / (t_{hmin} + \Delta t + t_p)$$

Travel time difference  $\Delta t$

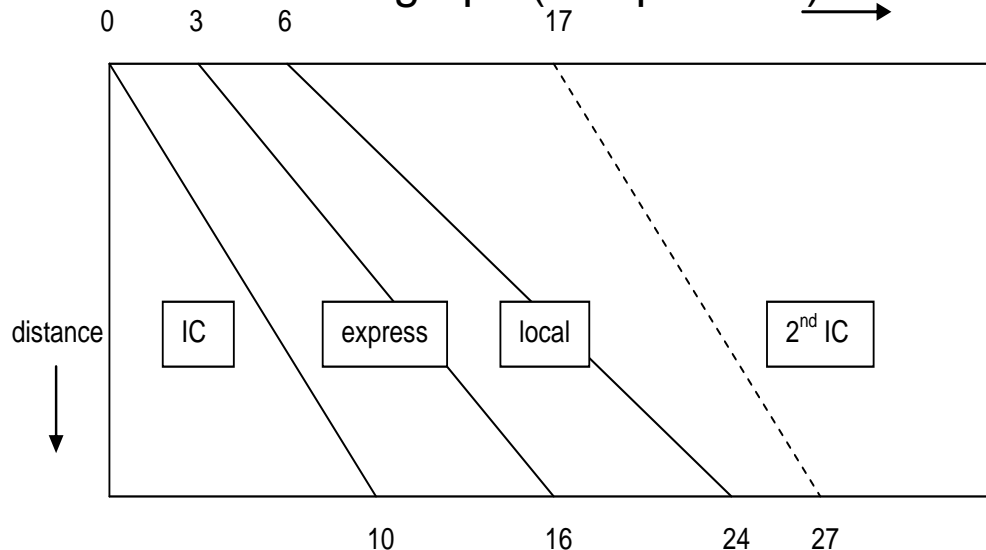
Buffer time:  $t_p$

# Example: macroscopic capacity estimation

Given: Arrival & departure times of 2 {IC, express, local} trains/h,  
timetable period  $T = 60$  min, minimum time headway 3 min

Train	Departure A	Arrival B	Departure A	Arrival B
Intercity	08:00	8:10	08:30	08:40
Express	08:03	08:16	08:33	08:46
Local	08:06	08:24	08:06	08:54

Train graph (compressed) →



Cycle time  $t_c = 17$  min

Number of cycles/ h  $n=2$

Mean time headway/cycle at  
- station  $t_h = 17/3 = 5.7 \approx 6$  min  
- track section =  $27/3 = 9$  min

Track occupation

$$\rho = 2 \times 17 / 60 = 57\%$$

$$= 2(3+3+(18-10)+3)/60$$

travel time difference  
between local and IC

Capacity

Max. cycle number/period

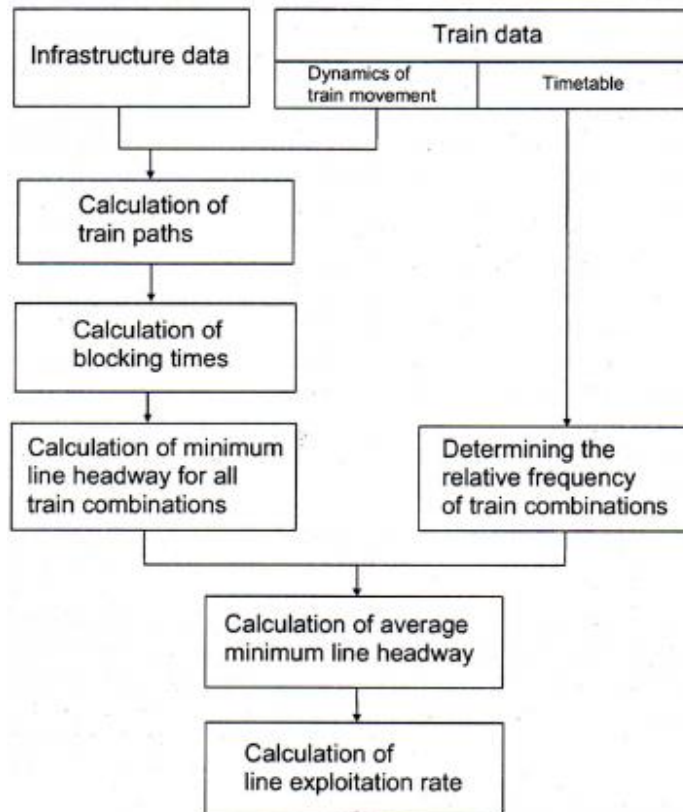
$$n_{\max} = 60/27 = 2.2$$

$$C = 60/9 = 6 \text{ trains/h}$$

# Drawbacks of macroscopic capacity estimation model

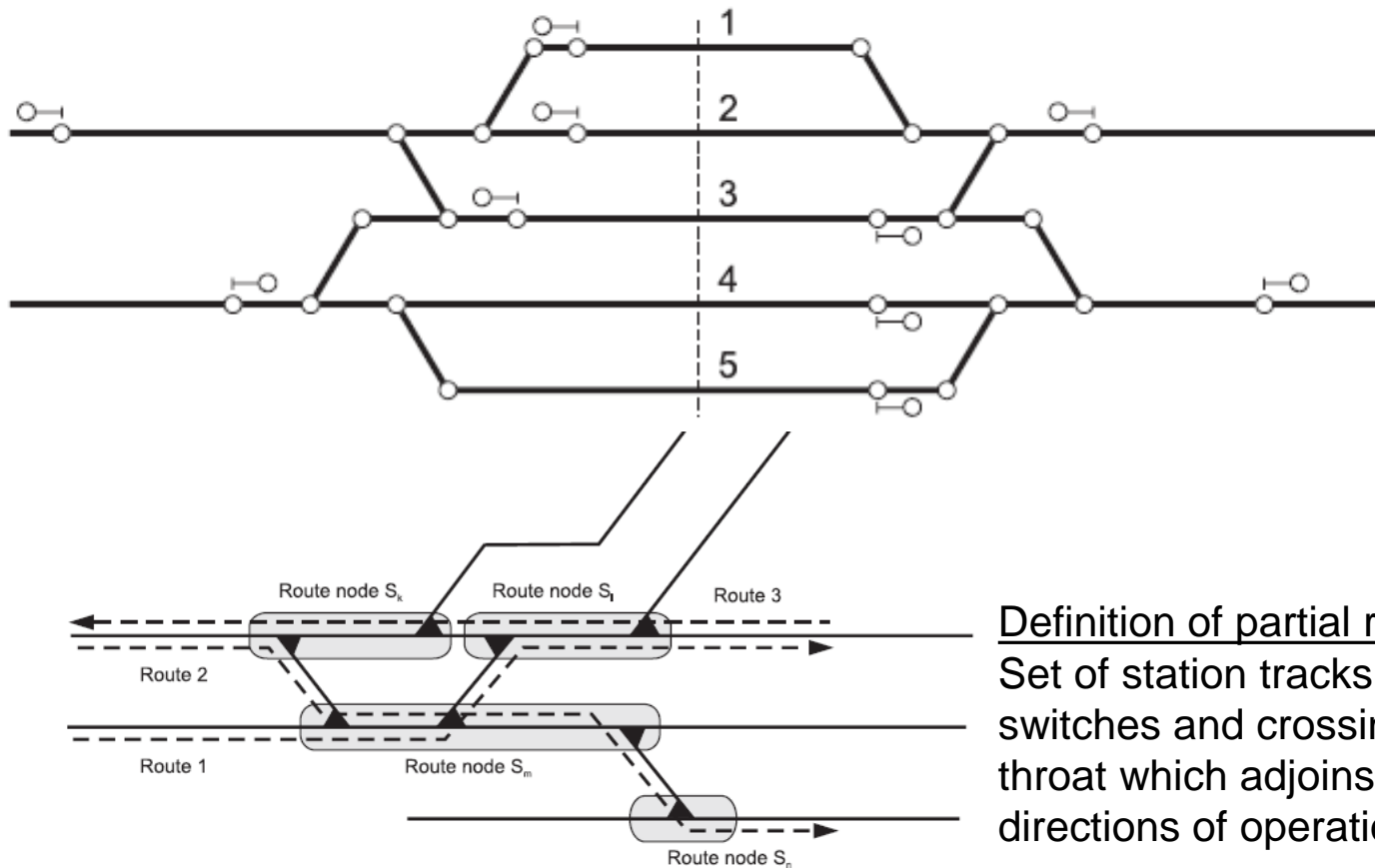
- Inaccuracy of scheduled travel (running and dwell) times
    - Linear train graphs: time loss due to acceleration, coasting and deceleration unknown/not disaggregated
    - Scale: times rounded-up to full minutes
    - Discrete point modelling of trains: variation of train length neglected
  - Validation of scheduled minimum time headways missing
    - Use of given standard minimum headway values (safety constraints)
    - Variation of train speed and minimum headway times neglected
    - Impact of ATP, ATC, ATO neglected
  - Timetable margins unknown
    - Standard running time supplements not verified nor differentiated
    - Amount of buffer times unknown
- ⇒ **Insufficient precision and reliability of capacity estimation!**

# Analytical capacity estimation according to UIC norm 406





# Microscopic model of station track yard and partial route nodes



Definition of partial route node:  
Set of station tracks including switches and crossings in a station throat which adjoins lines and directions of operation

# Microscopic infrastructure and rolling stock model



## Input

- Graph modelling of track infrastructure
  - Track section and platform lengths, radii, gradients and max. speed
  - Location and distance between signals, switches, crossings, insulation joints, overhead contact line separators,
- Specification of signalling and safety systems
  - Blocking and clearance, signal aspects, overlaps
  - Train detection, location of track circuits/axle counters/fouling points
  - Interlocking, set-up and (partial) release of routes
  - Train protection, train control
  - Train regulation
- Train length, weight, resistance, tractive effort-speed diagram

# Blocking time estimation

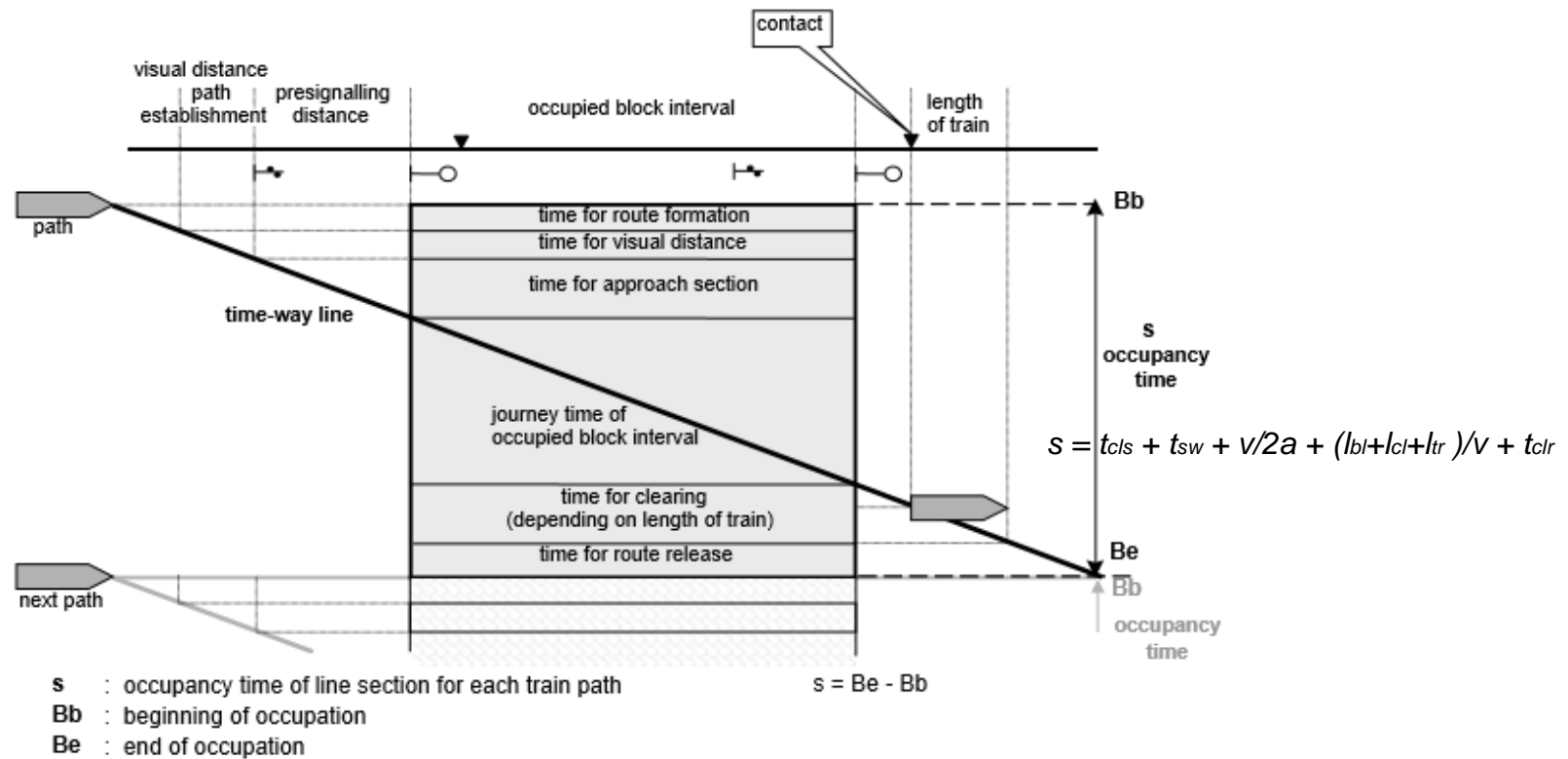
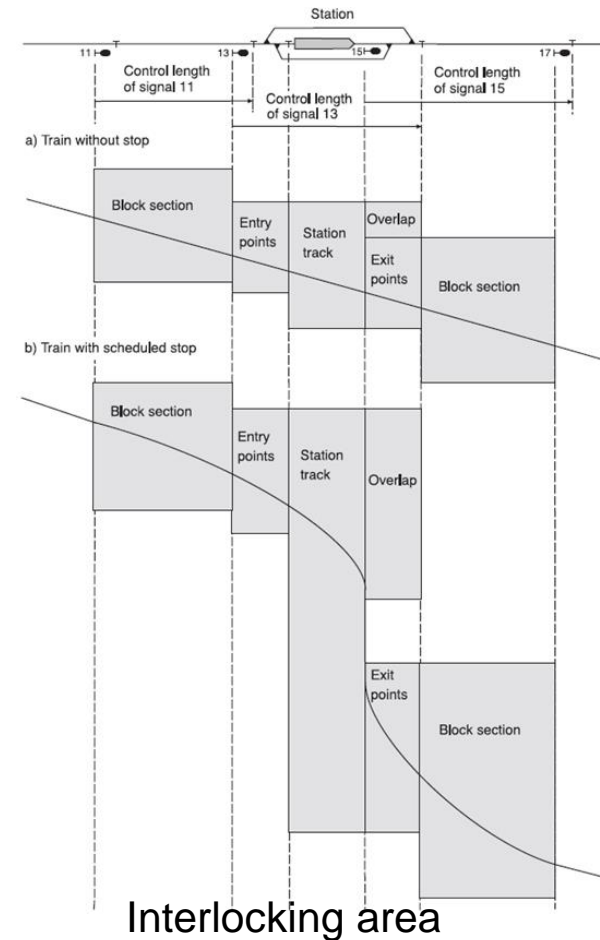
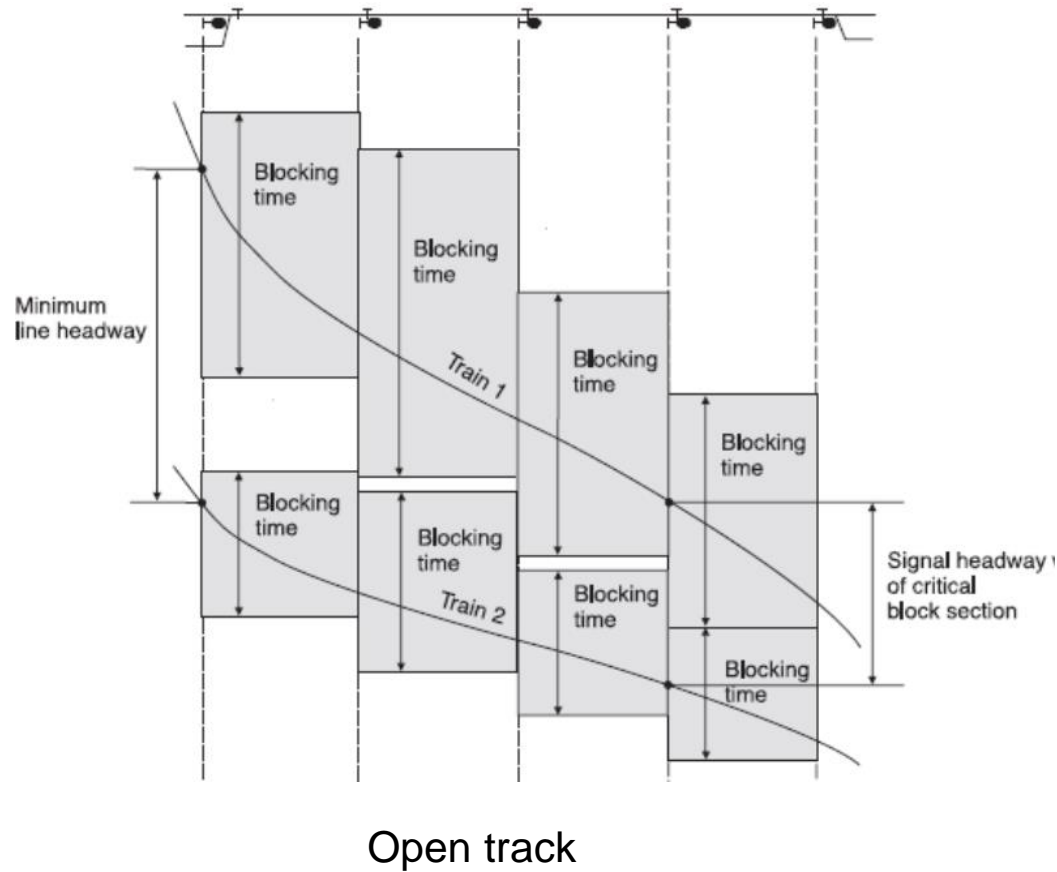


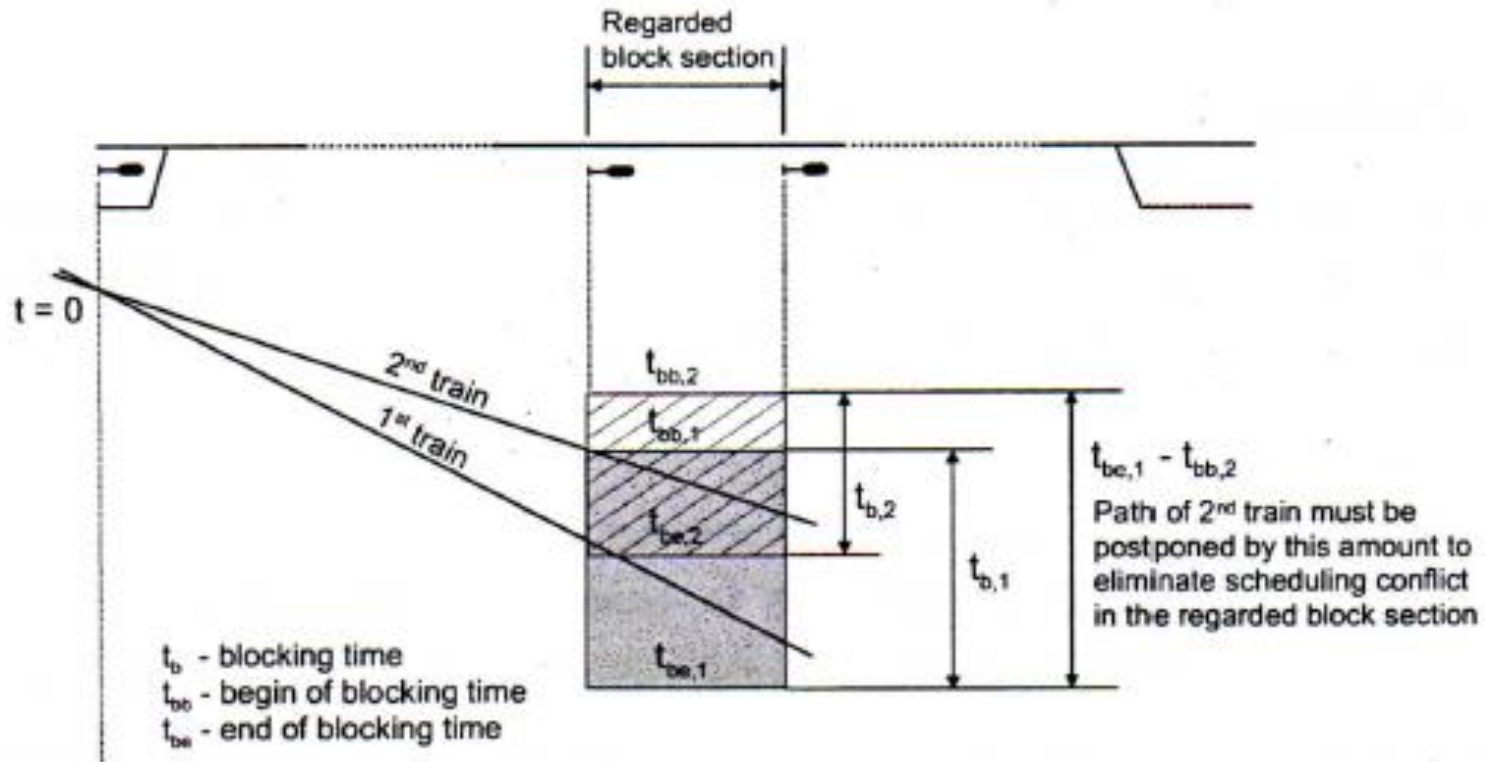
Fig. 15 - Physical attributes of a block section

Source Fig.15: UIC (2013)

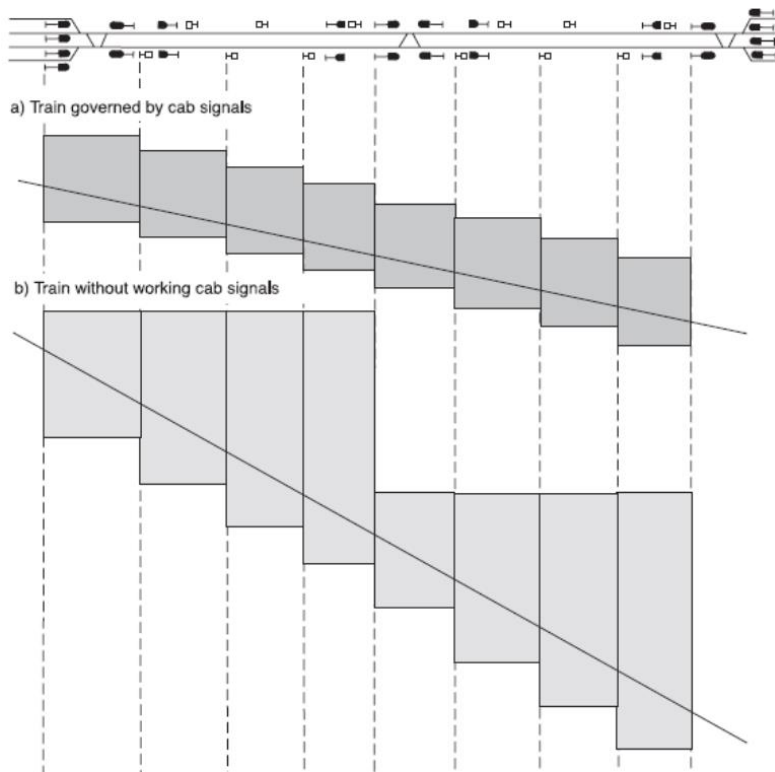
# Blocking time graphs



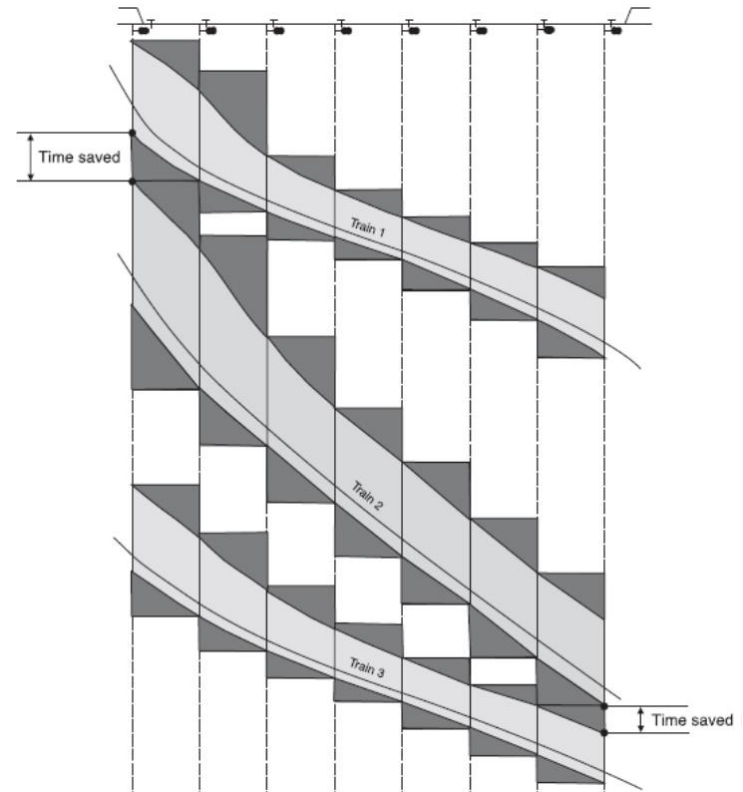
# Calculation of (scheduled) blocking time overlap



# Blocking time graphs for ATC and ATO



Signalling with(out) ATC



Signalling with ATO

# Timetable 'compression' of blocking time graphs

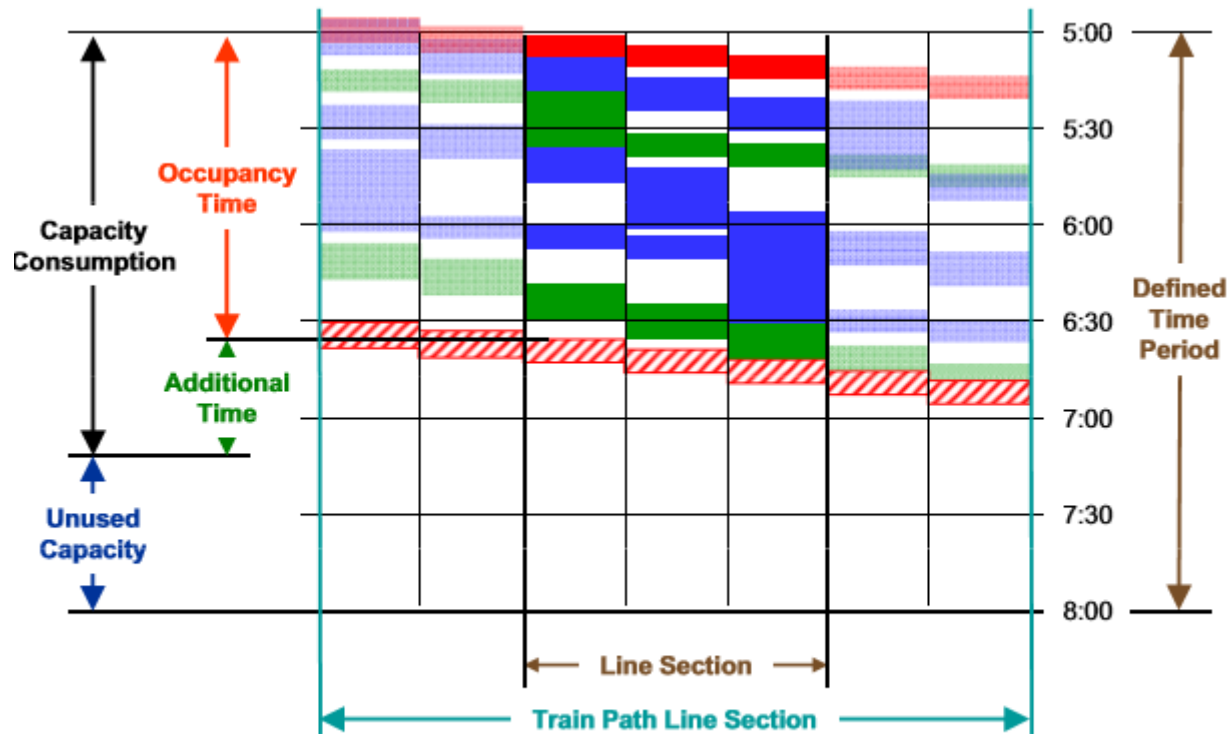
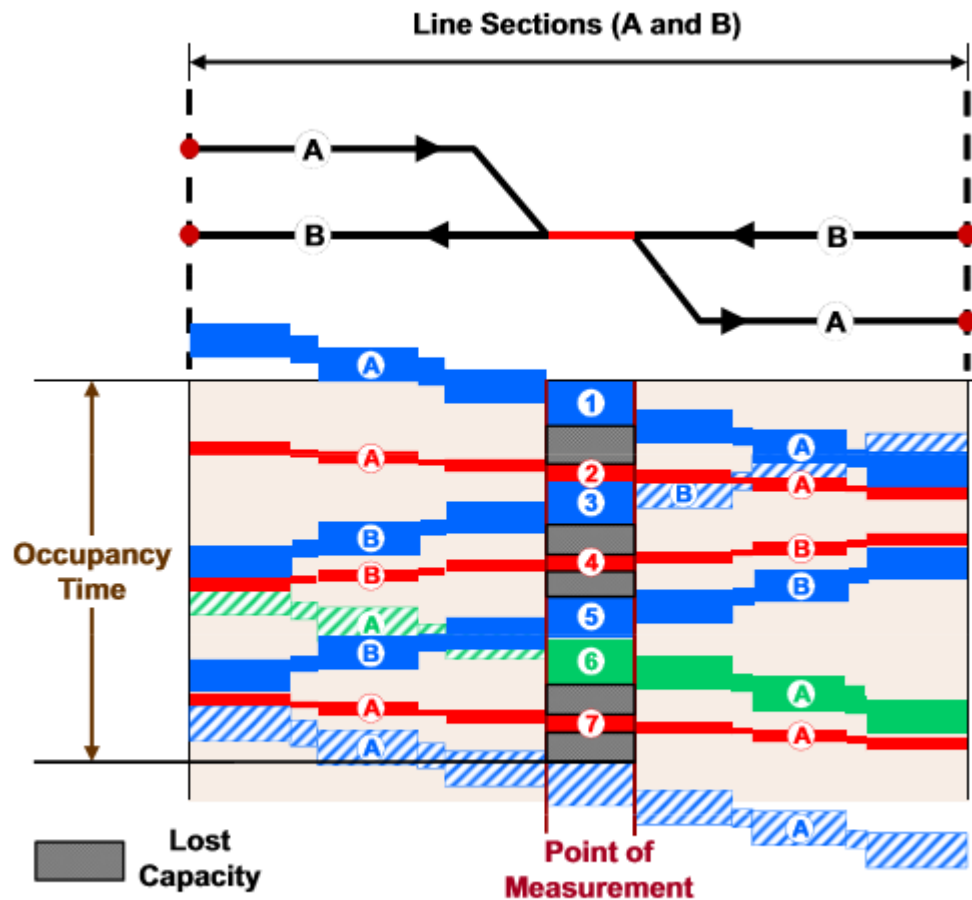


Fig. 17 - Capacity consumption and residual capacity of a line section

Source: UIC (2013)

# Timetable compression at single track section

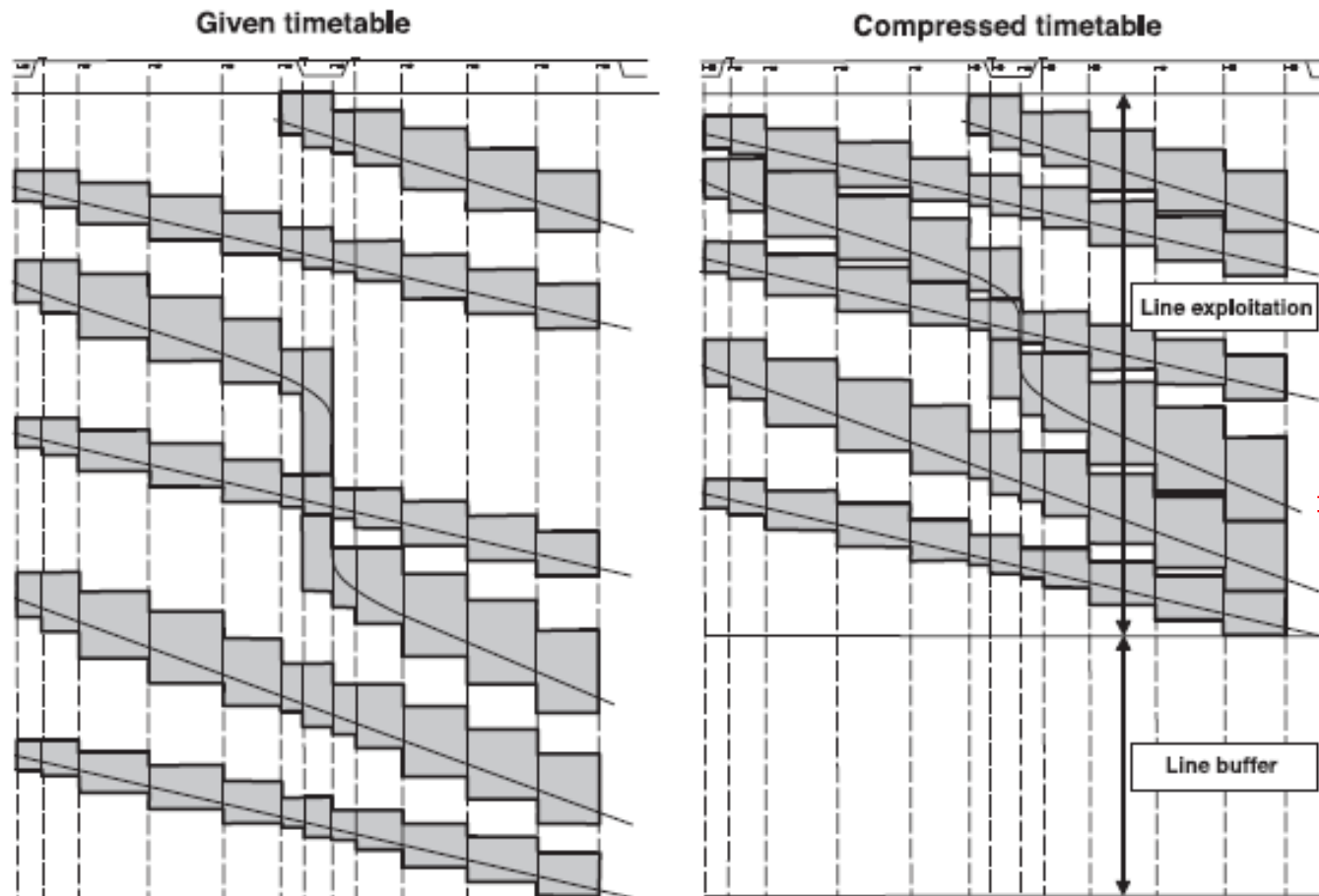


Source: UIC (2013)

Fig. 54 - Timetable compression of a bottleneck area



# Capacity consumption: 'compression' of blocking time diagrams



⇒ Drawbacks:  
timetable  
dependency,  
transferability?

# Microscopic capacity estimation

1. Estimation of blocking times  $t_{b/i}$  of trains per line
2. Determination of minimum headway time  $t_{h\ ij}$  between trains
  - at departure (according to different train sequences)
  - at arrival (stations)
  - at conflict points (merging/crossing of lines, long block, speed limit)
3. Determination of prevailing minimum headway times;  
mean minimum headway  $t_{hm} = \sum (t_{hij} \cdot p_{ij})$ ;  $p_{ij} = n_i \cdot n_j / n^2$
4. Estimation of (scheduled/feasible) number of train path  $n/n_{max}$
5. Estimation of total track occupation time of compressed  
(scheduled) train graph  $T_{toc} = n \cdot t_{hm}$
6. Estimation of (scheduled) track occupation  $\rho_s = T_{toc} / T$  [%]
7. Estimation of maximal track occupancy  $\rho_{max} = T_{toc\ max} / T$  [%]

# Example: Blocking time estimation

## Fixed block signal system

given

- train length  $l_{tr} = 350$  m
- train speed  $v = 160$  km/h
- block length  $l_{bl} = 2000$  m
- overlap  $l_{cl} = 50$  m
- switch time  $t_{cl} = 1$  s
- sight distance  $l_r = 300$  m
- reaction time  $t_r = 5$  s

Minimum headway distance between trains

$$d_{min} = v^2/2a + l_{bl} + l_{tr} + l_{cl} + v(t_r + t_{cl})$$
$$= 4647 \text{ m}$$

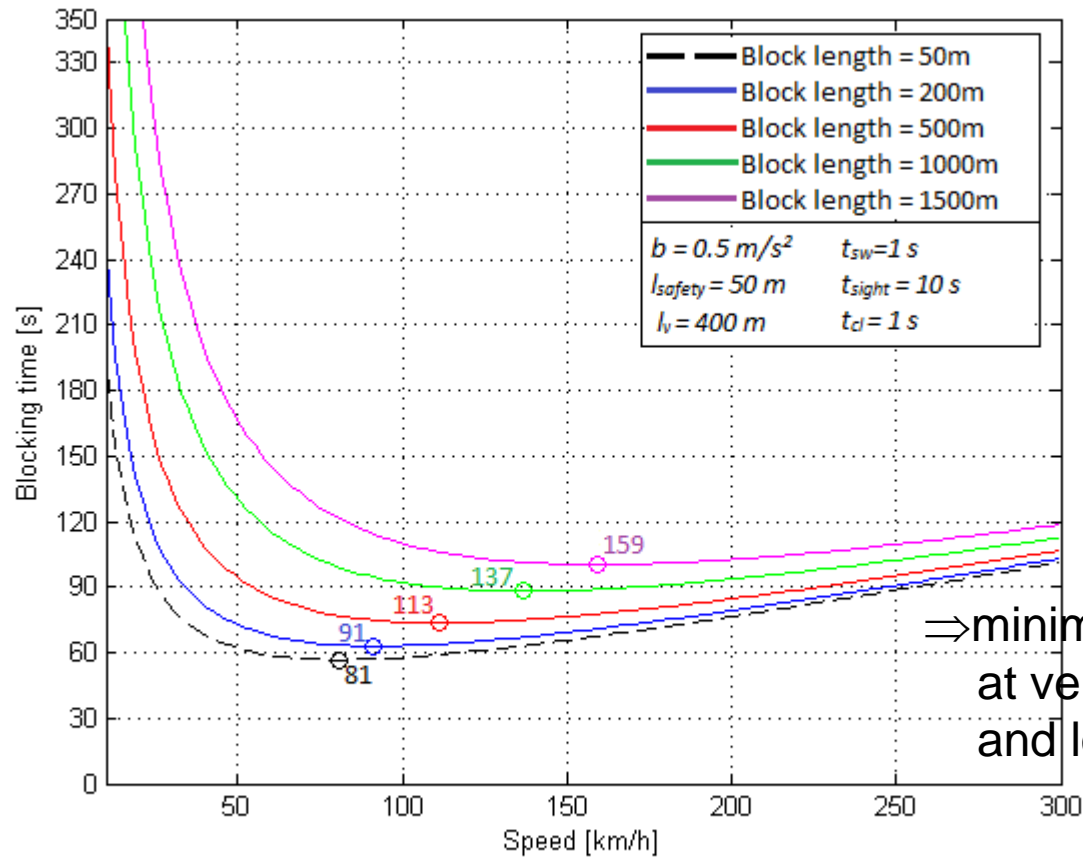
Minimum headway time

$$h_{min} = t_{cl} + v/2a + (l_{bl} + l_{tr} + l_{cl})/v + t_{clr}$$
$$= 104.5 \text{ s in case of separate distant signal}$$
$$= t_r + (l_r + 2l_{bl} + l_{tr} + l_{cl})/v + t_{cl}$$

in case of distant signal at main signal

$$= 111.6 \text{ s}$$

# Impact of block length and train speed on blocking time



$$T_{block} = t_{sw} + t_{sight} + (l_{br} + l_{block} + l_{safety} + l_v) / v + t_{cl}$$

# Simulation of track capacity consumption



## Macroscopic Models

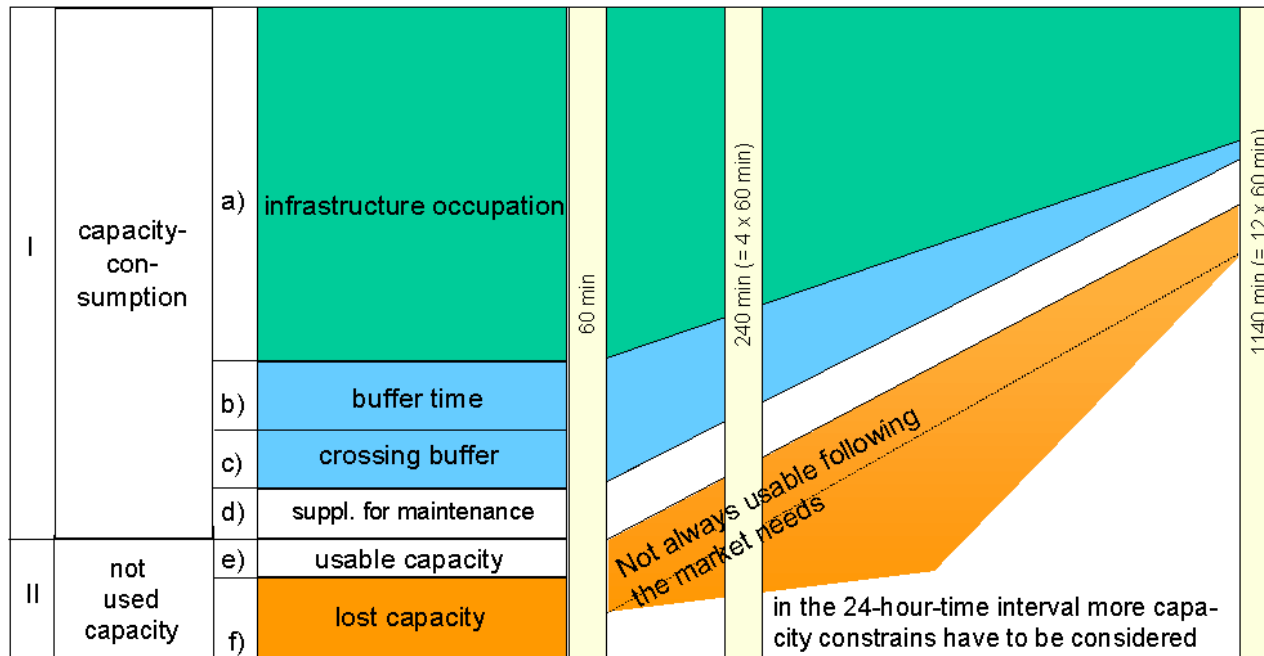
- Simple link-node graph
- Trains modelled as discrete points (without length)
- Running times rounded up/scaled in minutes  
possibly including acceleration/deceleration time loss
- Dwell times varying per station class and line (train type)
- Minimum headway times rule-based (implicit model of signalling and safety constraints)

⇒ **Shortcomings:**

- **Running time margin, buffer times and route conflicts unknown**

⇒ Microscopic capacity estimation **60 times** more accurate!

# Capacity consumption elements



Source: UIC (2004)

# Capacity consumption levels proposed by UIC

$$\text{Capacity Consumption [\%]} = \frac{\text{Occupancy Time} + \text{Additional Times}^*}{\text{Defined Time Period}} \times 100$$

Type of line	Peak hour	Daily period
Dedicated suburban passenger traffic	85 %	70 %
Dedicated high speed lines	75 %	60 %
Mixed traffic lines	75 %	60 %

$$\text{Capacity Consumption [\%]} = \frac{\text{Occupancy Time} \times (1 + \text{Additional Time Rate})}{\text{Defined Time Period}} \times 100$$

$$\text{Additional Time Rate [\%]} = \left[ \frac{100}{\text{Occupancy Time Rate}} - 1 \right] \times 100$$

Table 3 : Proposed occupancy rates and additional time rates for nodes

Type of node area	Concatenated Occupancy Rate	Additional Time Rate
Switch area	60 % ... 80 %	67 % ... 25 %
Track area	40 % ... 50 %	150 % ... 100 %

Table 2 : Proposed additional time rates for lines

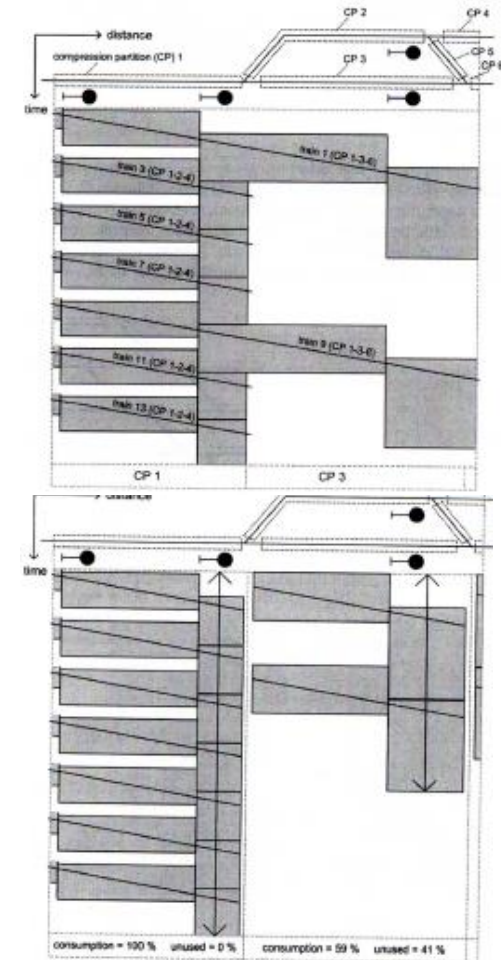
Type of line	Peak hour	Daily period
Dedicated suburban passenger traffic	18 %	43 %
Dedicated high-speed line	33 %	67 %
Mixed-traffic lines	33 %	67 %

“Acceptable quality of service is represented by capacity consumption values of up to and including 100%“ (p. 30)

Source: UIC (2013)

# Shortcomings of UIC capacity estimation method

- Enrichment of “compressed” blocking time graph not feasible for links with changed number of tracks (branching, overtaking)
- Capacity of single track operated bi-directionally depends on market acceptance (fleeting of train paths)
- Capacity of station tracks and route nodes depends on routing and synchronisation requirements for passenger transfer connections
- Essentially still deterministic model  
⇒ Stochastic modelling of process times necessary to determine robustness



Source: Lindner, 2011



# Conclusions

- Track capacity is influenced by the timetable, infrastructure, signalling and safety systems, rolling stock, weather and human behaviour
- Macroscopic capacity estimation models simplify infrastructure, route and signalling constraints but can support strategic network and timetable planning
- Microscopic capacity models can accurately estimate minimum headways, capacity consumption and timetable margins for different signalling and safety systems; calibration of real train speed profiles and dwell times needed
- UIC compression method is deterministic and requires multiple stochastic simulation runs to estimate capacity & stability of different timetable options
- Impact assessment of train speed changes/acceleration/deceleration on minimum headway times, capacity and train delays remains necessary
- Which is the capacity of the new HSR terminal in Hong Kong?

# Literature



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The performance of many railway networks and the quality of service offered is becoming more and more critical. The main issues to be addressed are the increasing traffic volumes and making the best use of the available capacity, at the same time resolving train scheduling and management problems.

This is an updated, revised and extended edition of 'Railway Timetabling & Traffic', published in 2008. It describes the state-of-the-art methods of railway timetabling and optimisation, capacity estimation, train operations analysis and modelling, simulation, rescheduling and performance assessment. The intention is to stimulate their broader application in practice and to highlight current and future research areas. It is directed at academics, Masters and PhD students, as well as professionals from the railway industry. It will also be of interest to the public authorities that tender, monitor and perhaps fund railway service provision. The overall aim is to improve the attractiveness and efficiency of the train services which can be offered to the public.

The key to achieving a higher efficiency and quality of train operations is an awareness of the impact of availability, reliability and robustness of the subsystems on train processes. A deeper insight into the probability of incidents and the propagation of train delays depends on a thorough analysis of real world railway operations and the feedback obtainable. This leads to an optimisation of the timetable and a network-wide improvement in traffic management performance.

This know-how should increase the efficiency of the railway system, making it more attractive for regular, occasional and new customers, and ensure that the railways continue to innovate. They will then be able to make the maximum contribution possible to the transport needs of the future.

Hansen · Pachtl

Railway Timetabling & Operations

Editors: Ingo Arne Hansen · Jörn Pachtl

# Railway Timetabling & Operations

Analysis · Modelling · Optimisation  
Simulation · Performance Evaluation



Eurail  
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2nd revised  
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