دانشگاه صنعتی اصفهان
دانشکده مهندسی حمل و نقل

حمل و نقل ریلی

ظرفیت (Capacity)

قسمت اول

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بهار ۱۳۹۴

- ✓ Definition of railway capacity
- ✓ Parameters of capacity
- ✓ Types of capacity
- ✓ Methods to evaluate capacity
- ✓ Capacity consumption
- ✓ References

- It is relatively straightforward to determine the capacity on **roads**:

it is normally determined merely as **vehicles per hour**.

- Capacity on **railways** is, however, more difficult to determine because:

Capacity depends on: **infrastructure**, **timetable** and **rolling stock** ... (Kaas 1998b).

Railway Capacity

What does it mean?

There are different definitions..

- The capacity of a railway line is the ability to operate trains with an acceptable punctuality (Skartsæterhagen 1993)
- The theoretical capacity is defined to be the maximal number of trains that can be operated on a railway link (Rothengatter 1996)
- Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan (Krueger 1999)
- The only true measure of capacity therefore is the range of timetables that the network could support, tested against future demand scenarios and expected operational performance (Wood, Robertson 2002)
- Capacity can be defined as the capability of the infrastructure to handle one or several timetables (Hansen 2004b)
- Capacity is defined as the maximum number of trains which can pass a given point on a railway line in a given time interval (Longo, Stok 2007)
- Capacity may be defined as the ratio between the chosen time window and the sum of average minimum headway time and required average buffer time (Oetting 2007)
- The capacity of the infrastructure is room on the track that can be used to operate trains (Jernbaneverket 2007)
- The number of trains that can be incorporated into a timetable that is conflict-free, commercially attractive, compliant with regulatory requirements, and can be operated in the face of anticipated levels of primary delay whilst meeting agreed performance targets (Barter 2008)

Reference: Landex, 2008

(Longo, Stok 2007) Railway Capacity is:

maximum number of trains which can pass a **given point** on a railway line in a **given time interval**

[UIC 406] Railway Capacity is:

"the total number of possible train paths in a defined time window, considering the actual path mix or known developments, respectively"

- Railway capacity is a **complex**, **loosely-defined** term that has **numerous meanings** (Krueger 1999).
- Definitions of Railway capacity **differ by country** (Rothengatter 1996).
- Railway capacity is **not deterministic**.
- It is extremely dependent on how it is used.
- Physical & dynamic variability of train characteristics makes capacity dependent on **particular mix of trains** and **order** in which they run on the line.
- It varies with changes in **infrastructure** and operating conditions (Abril, 2008)

Calculating Railway Capacity

Why?

- Although railway capacity is **complex to understand**, it is essential for determining the **amount of traffic that can be moved** over a rail system and the **degree of service** and reliability that can be expected.
- the effective management and **utilization of assets** is becoming more important as railways try to **reduce costs**, improve service and **handle increased traffic** (Krueger 1999).

- Satisfying a market demand with 2 simultaneous properties:

high average speed

+

high heterogeneity (a mix of fast Intercity Express, Intercity and slower Regional trains) serving all stations.

- Consequence: It is **not** possible to operate **as many trains as** when all trains are operated with the **same speed** and **stop pattern**.

- How to operate more trains?

- having a less mixed operation

- How to have a less mixed operation?

- Having lower average speed (fast trains are adapted to te slower trains)

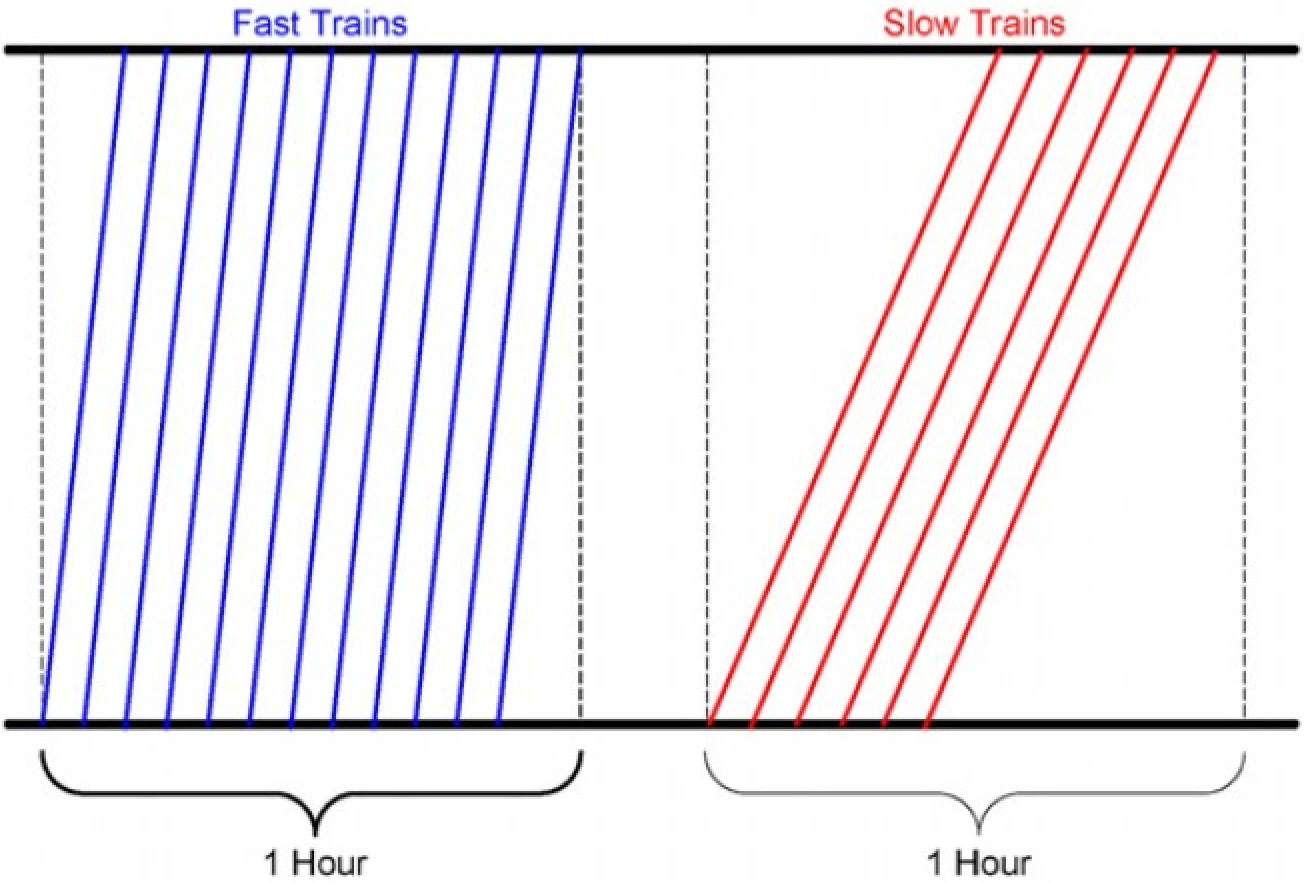
Time-table Stability ↑ → Capacity ↑

Average Speed ↑ Heterogeneity ↑ → Capacity ↓

Average Speed ↑ (Homogenous traffic) → Capacity ↑

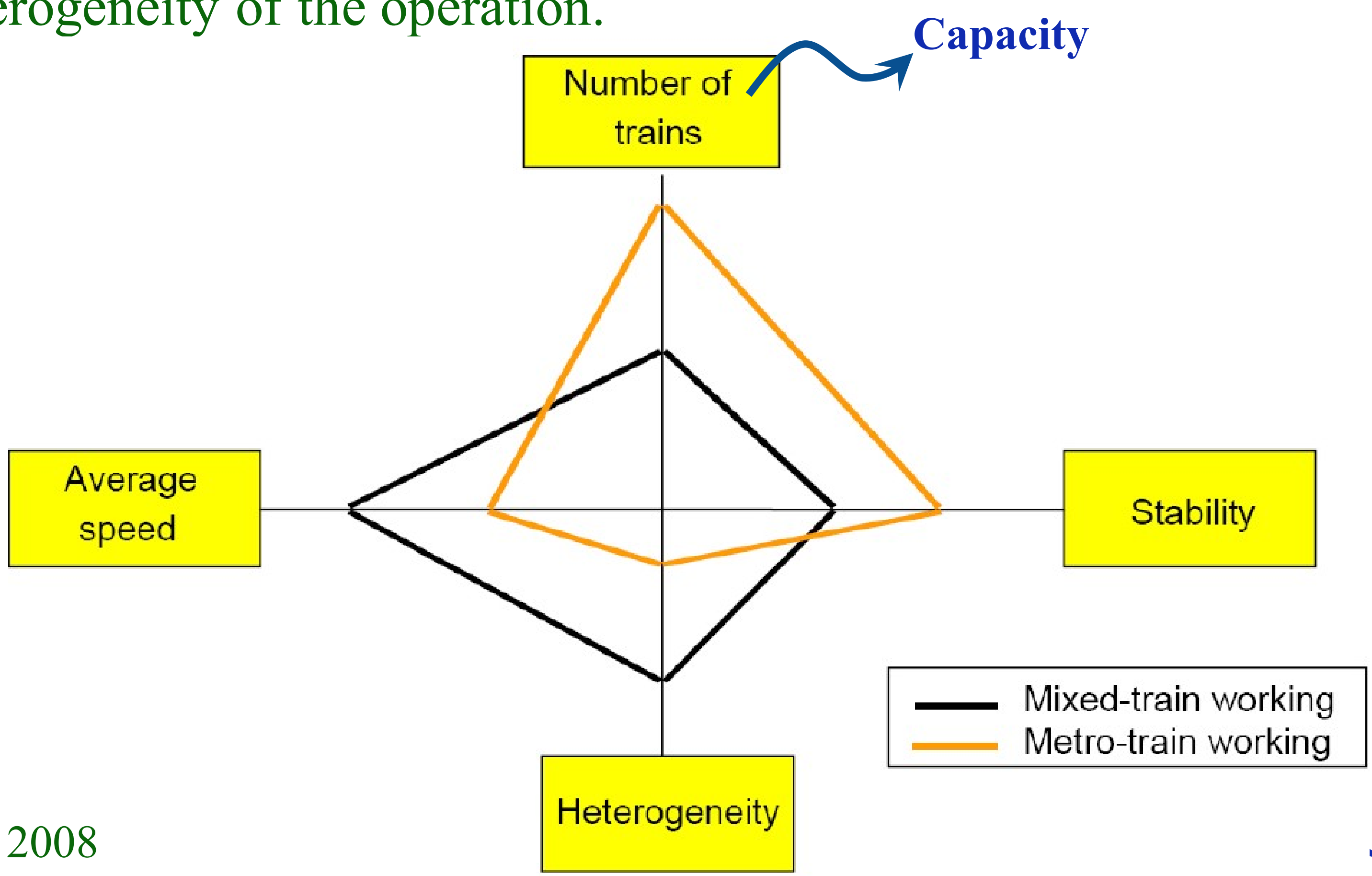
Heterogeneity ↑ → Capacity ↓

Impact of speed on the Capacity



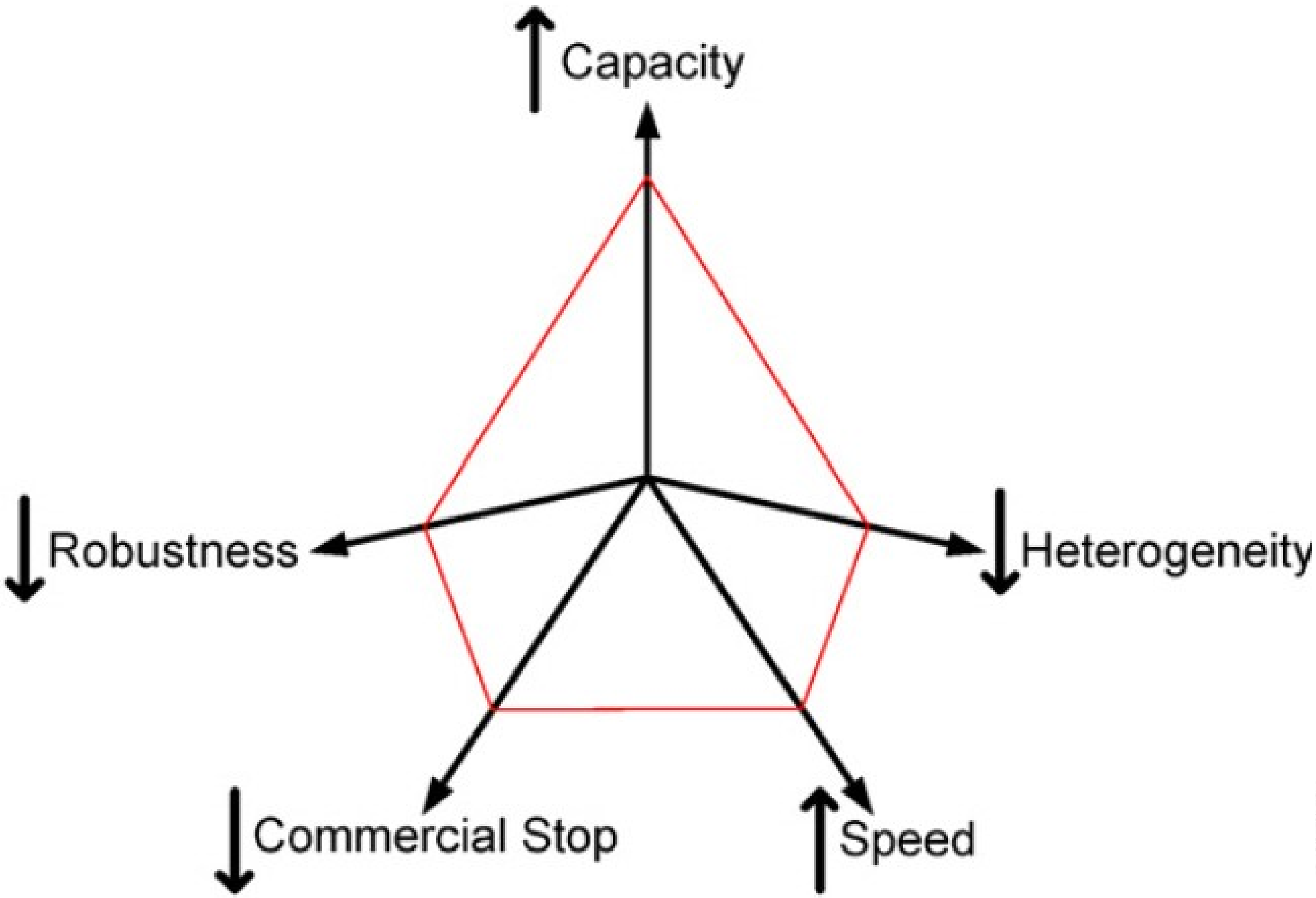
❑ Capacity (Number of trains) is a balanced mix of:

- ✓ Stability of the timetable (punctuality)
- ✓ Level of average speed achieved
- ✓ Heterogeneity of the operation.



Landex, 2008

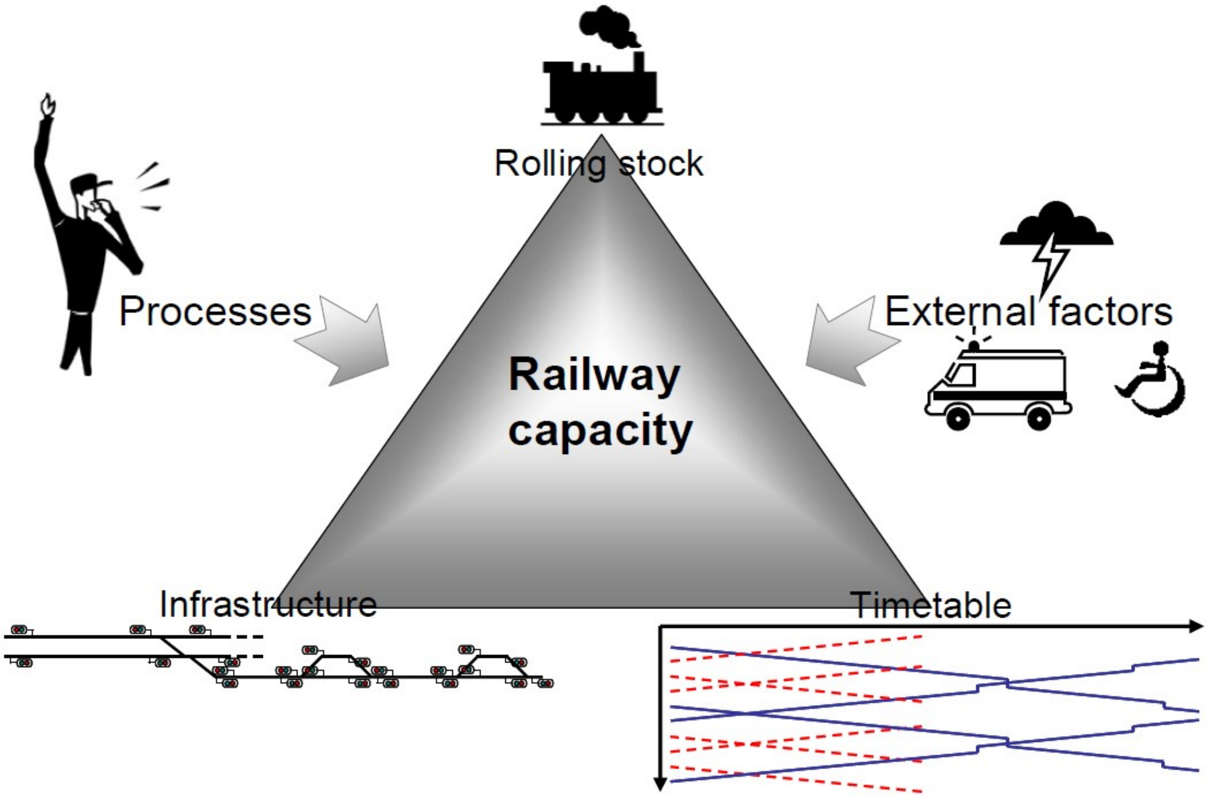
The main parameters that affect capacity



Railway capacity depends not "only" on: **rolling stock**, **infrastructure** and **timetable**,

sometimes the capacity is reduced due to processes in the operation such as:

- ✓ time consuming for **staff schedules**, **congestion of passengers** at stations etc.
- ✓ external factors such as the **weather**, breakdowns and **accidents**.



Nevertheless, attempts are made to minimize this influence by, for example, adding time supplements in the timetable.

Main Parameters of capacity

- **Infrastructure parameters:**
  - ✓ Block and signalling system
  - ✓ Single/double tracks
  - ✓ Network effects
  - ✓ Track structure and speed limits
  - ✓ Length of the subdivision

- **Traffic parameters:**
  - ✓ New or existing lines
  - ✓ Train mix
  - ✓ Regular timetables:
  - ✓ Traffic peaking factor
  - ✓ Priority

- **Operating parameters:**
  - ✓ Track interruptions
  - ✓ Maximum trip time threshold
  - ✓ Time window
  - ✓ Quality of service, reliability, or robustness

❑ **Infrastructure parameters:** Block and signalling system

- ✓ The signals help extend the train driver's **visibility**, so it allows **greater speeds**.
- ✓ The role: to keep trains at a **safe distance**.
- ✓ Two types of systems: fixed-block signaling + moving-block signaling.

Fixed- block signaling system:

- ✓ the **position** of each train is known **only** by the block section(s) that it occupies.
- ✓ The separation between trains is maintained by imposing restriction that **each block section** be occupied by at most **one** train at a time.
- ✓ Block section lengths, train speeds and train lengths are, therefore, important parameters.

Moving-block signalling system:

- ✓ the position of each train is known **continuously**, thus permitting **better regulation** of the **relative distances**.
- ✓ This requires an **efficient communication system** between line signals, cabs and control centres.

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- **Infrastructure parameters:** Single/double tracks

✓ It is **not** as simple as **multiplying** the number of tracks.

✓ A double-track line usually have a capacity of **more than two times** rather than a single track; however, a four-track line rarely increases capacity by more than 50% over a double line (Kittelson and Associates, 2003).

✓ Adding a second track **may not eliminate** the problem because the **station** is the real bottleneck.

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- **Infrastructure parameters:** Track structure and speed limits

- ✓ The condition of the **rails, ties, and ballast** dictate the weight and type of equipment that can be used on the line, as well as the speeds allowed on the line.
- ✓ The speed limits are regulated by means of **speed profiles**, which take into account physics, safety, comfort, train types, etc.

- **Infrastructure parameters:** Length of the subdivision

- ✓ If the **length** of the subdivision increases, so does the transit **time** of trains.
- ✓ **"Bottleneck"** (or the most constrained line section) is traditionally introduced as the bounding factor to the overall capacity.
- ✓ Capacity can potentially **increase** as the line sections between the stations become **shorter**, and **more auxiliary tracks** are available at the station to allow crossing and overtaking operations.

- **Traffic parameters:** New or existing lines

- ✓ The solution is generally different when new (i.e., to be designed) or current (i.e., available) lines are considered.
- ✓ In the second case, which is by far the most common, **several constraints are already set**, and the traffic to be added often interface an available capacity problem, which is more constrained.

❑ **Traffic parameters:** Train Mix

- ✓ Railway capacity is very **much dependent** on traffic mix.
- ✓ The **ideal** case is when all trains are the **same** or have the same speed.
- ✓ As the **mixture** of different trains increases, more **interferences** are generated.
- ✓ Besides maximum speed, other rolling stock characteristics such as **acceleration** and **deceleration** are also important.

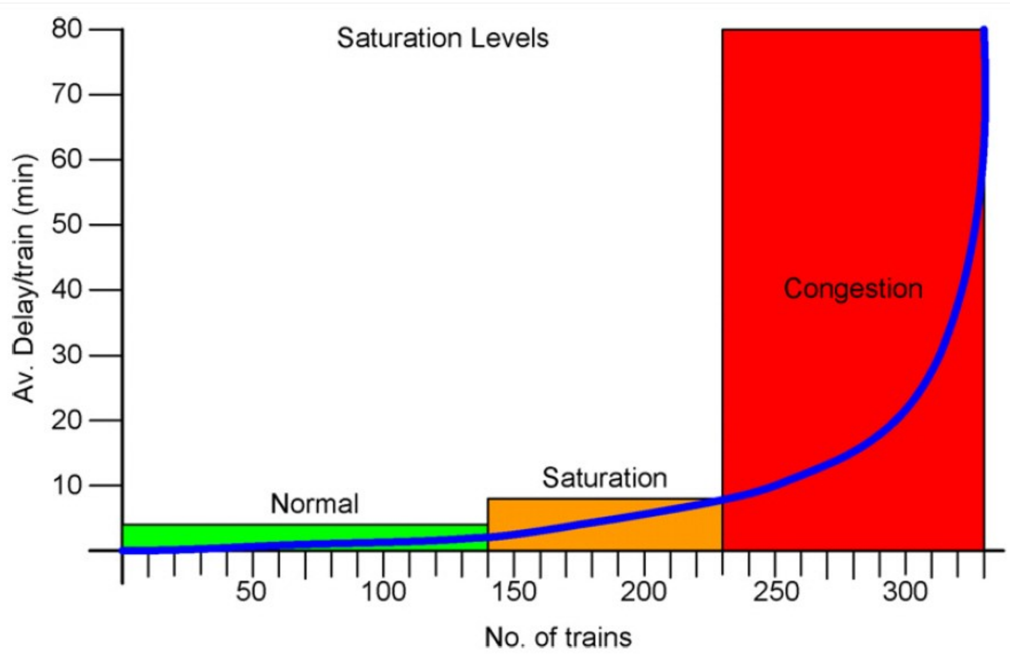
- **Traffic parameters:** Priority

- ✓ Train priorities **decrease capacity** because priority trains are given **preferential treatment** over lower priority trains, which results in **increased delays**.
- ✓ As a rule, the **greater** the **number of priority classes**, the **less capacity** is available.

- **Operating parameters:** Track interruptions

- ✓ These can be **planned events** (maintenance times, commercial stops, etc.) and **unplanned events** (train failures, broken rails, etc.) that take a track out of service.
- ✓ These interruptions directly **reduce the number of hours available** to move trains.

- **Operating parameters:** Quality of service, reliability, or robustness
  - ✓ **Random** minor disturbances and **failures** occur in the real management reducing the theoretical capacity.
  - ✓ So, some **buffer times** must be added to design a **robust** timetable.
  - ✓ A balance between **service reliability** and physical **capacity** is needed to find the economically optimal level of capacity.
  - ✓ the average delays increase **exponentially** when the number of trains exceeds the saturation level and then network reliability is lost.
  - ✓ increasing the number of trains over the saturation level is **not profitable**.



Different Types of Railway Capacity:

✓ **Theoretical capacity:**

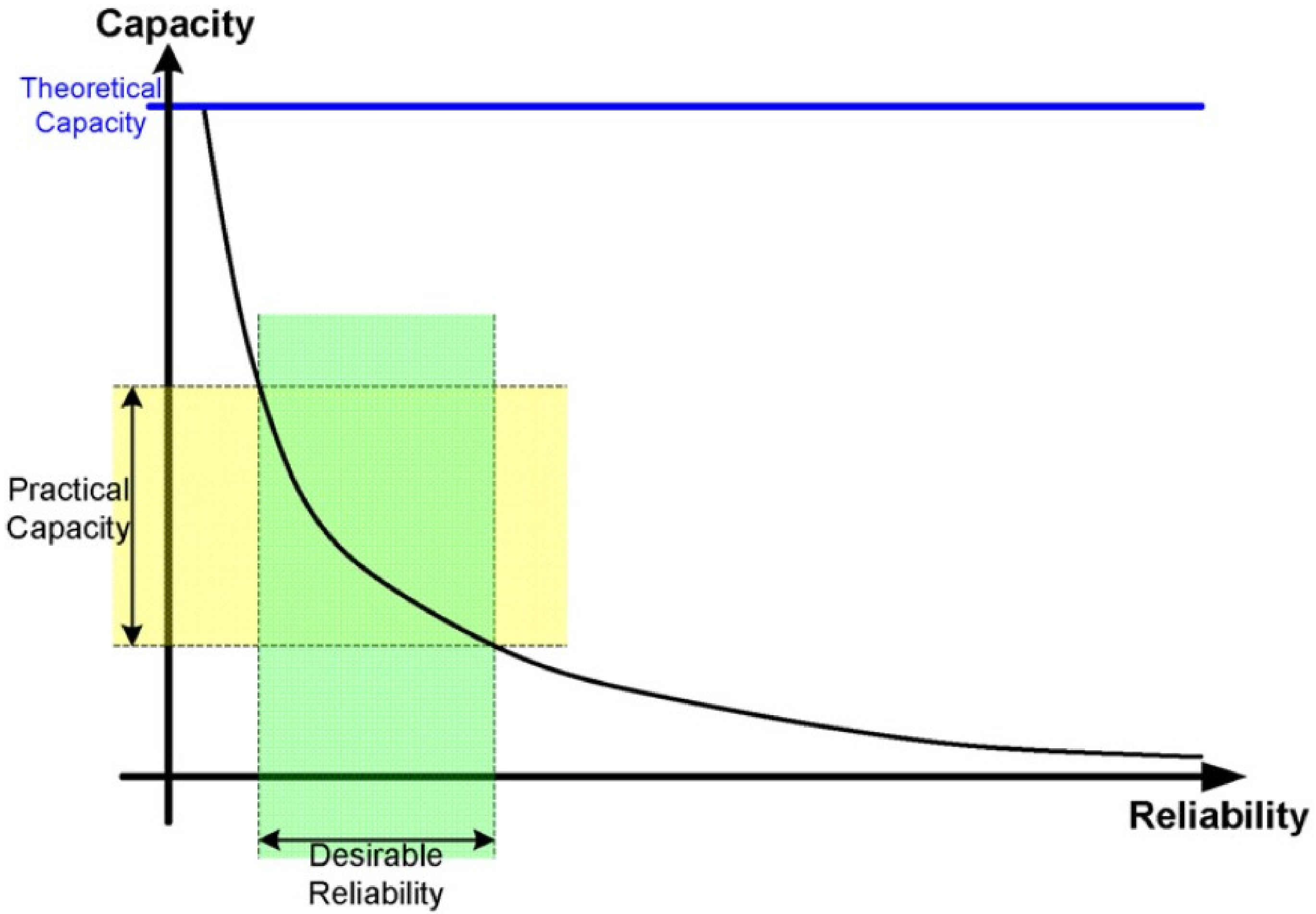
- It is the number of trains that could run over a route, during a specific time interval, in a **strictly perfect**, **mathematically** generated environment, with the trains running permanently and ideally at **minimum headway**
- It is an **upper limit** for line capacity.
- it assumes that traffic is **homogeneous**, that all trains are identical, evenly spaced throughout the day with no disruptions.

Different Types of Railway Capacity:

✓ **Practical capacity:**

- It is the **practical** limit of **“representative” traffic volume** that can be moved on a line at a reasonable level of reliability.
- The “representative” traffic reflects the **actual train mix, priorities**, etc.
- It is usually around **60–75%** of the theoretical capacity.
- Practical Capacity relates the ability of a specific combination traffic to move the most volume within an **expected service level**.

Practical capacity involves the desirable reliability level



✓ Analytical Methods

- very **simple** models using **mathematical** formulas
- They usually obtain theoretical capacities and determine practical capacities either as a **percentage** of the theoretical capacity or by including **regularity margins**

Advantages:

They may be a good start for **identifying bottlenecks**

Disadvantages:

Analytical **results vary** from one method to another, depending on what type of parameters they model.

Analytical models are very **sensitive to parameter** input and train mix variations.

- For example: Scott, UIC 405 (1996)

Scott

$$C = \frac{1440 - W}{T + t} \times K$$

- **Capacity (no. of trains)** → C
- **Required time for maintenance** → W
- **Efficiency Coefficient** → K
- **Transit time of slowest freight train in critical block** → T
- **Headway between trains** → t

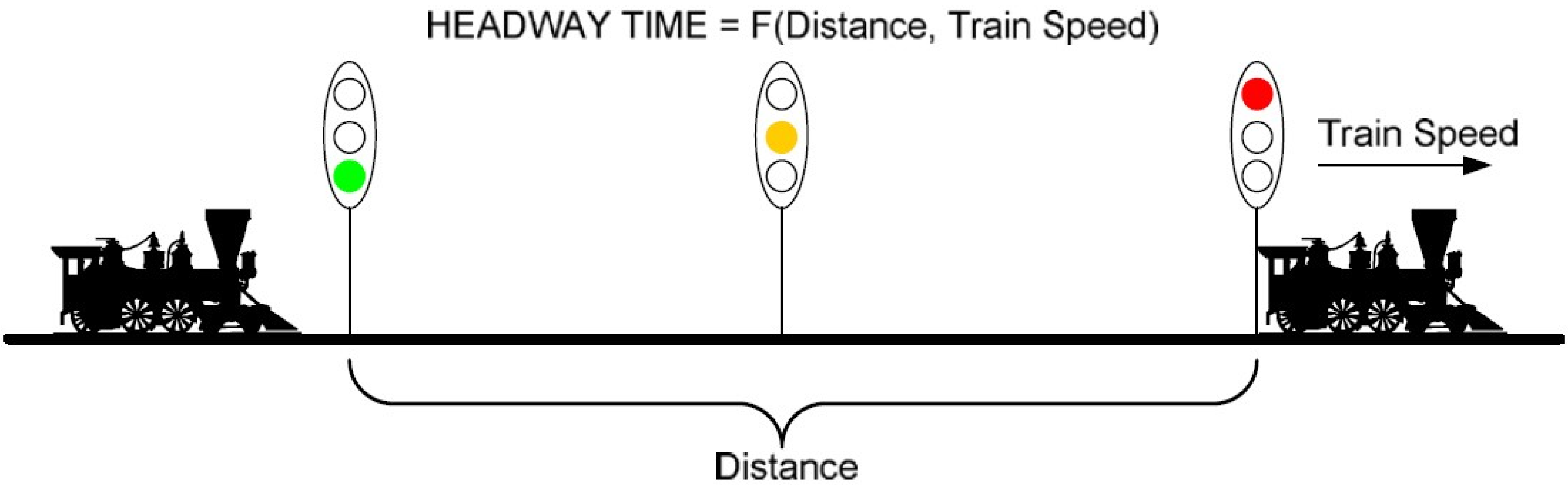
K: based on planned and unplanned stops, rate of unpredictable delays, intersections, priorities, ...

UIC 405

$$C = \frac{T - W}{t_{fm} + t_r + t_{zu}}$$

- C: Capacity (no. of trains)
- W: Required time for maintenance
- t_{fm}: Average of Transit time of all trains departed
- t_r: running time margin
- t_{zu}: Added time

Headway time between consecutive trains



✓ Optimization Methods

- They provide **much better** solutions than purely analytical formulae.
- They are based on obtaining **optimal saturated timetables**.
- The optimal timetables are obtained by mathematical techniques (**MILP Formulations** and **Enumerative algorithms**).

- For example: UIC 406 (2013):

It proposes a new method that is included in the framework of the optimization methods which is based on a **timetable compression method**.

- For example: EUROPE-TRIS project:

A scheduling algorithms was developed: FLOU (Flow Line Optimal Utilization) to integrate **maximum trains** at **minimum cost** in a given timetable

✓ Simulation Methods

- A simulation is the **imitation** of an operation of a real-world system.
- Simulation methods provide a model, which is **as close as possible to reality**, to validate a given timetable.
- For example:

MultiRail

OpenTrack

SIMONE

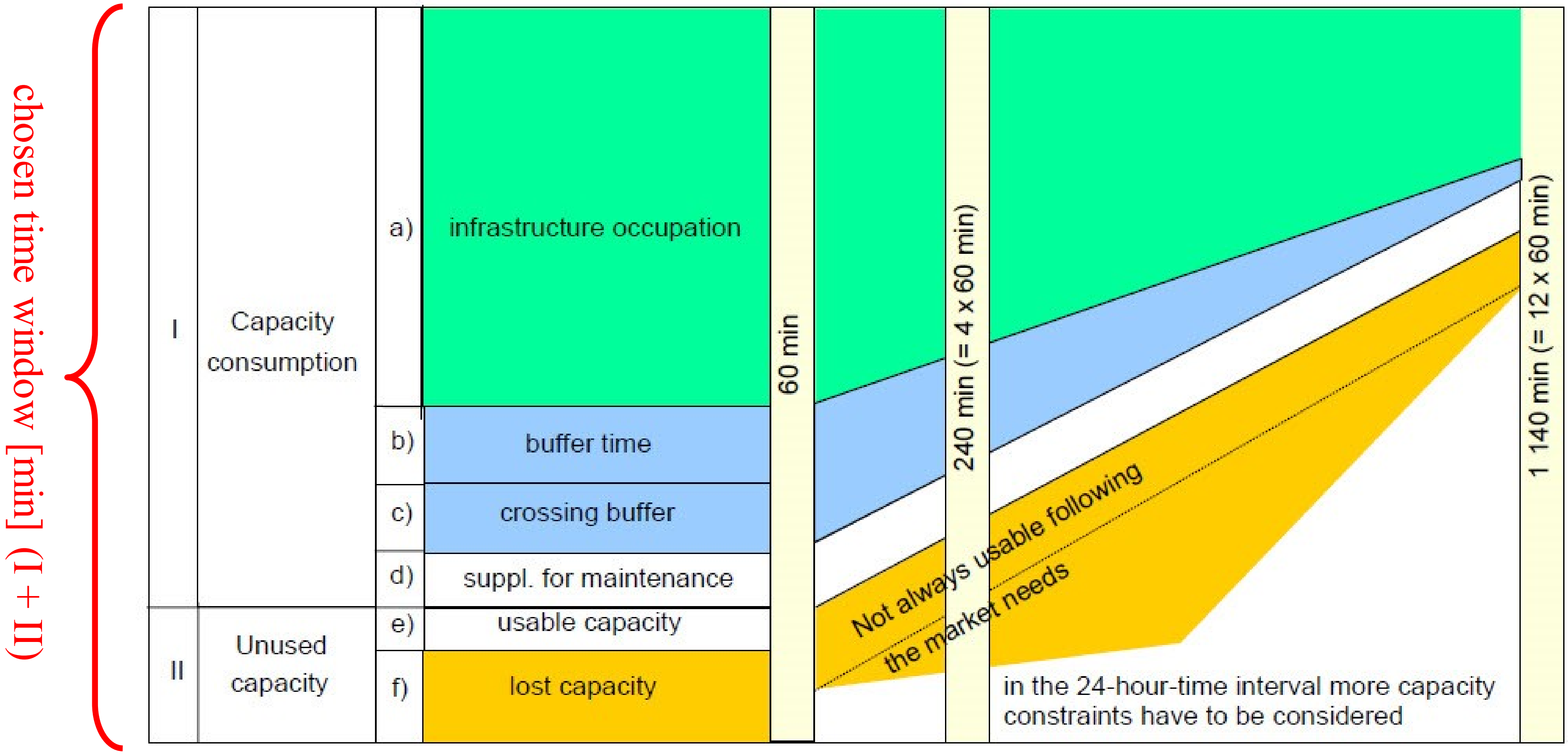
Capacity Consumption [UIC 406 (2013)]:
Utilisation of an infrastructure's physical attributes along a given section, measured over a defined time period

Concept of "Capacity Consumption" is exactly the same in two versions: UIC406 (2004) & UIC406 (2013)

UIC 406 (2004)

$$K = \frac{k \times 100\%}{t_U}$$

- K: capacity consumption [%]
- k: total consumption time [min]
- t_U: chosen time window [min]



k (Total consumption time) →

A: infrastructure occupation [min]
B: buffer time [min]
C: supplement for single-track lines [min]
D: supplements for maintenance [min]

UIC 406 (2004)

UIC 406 (2013)

total consumption time [min]

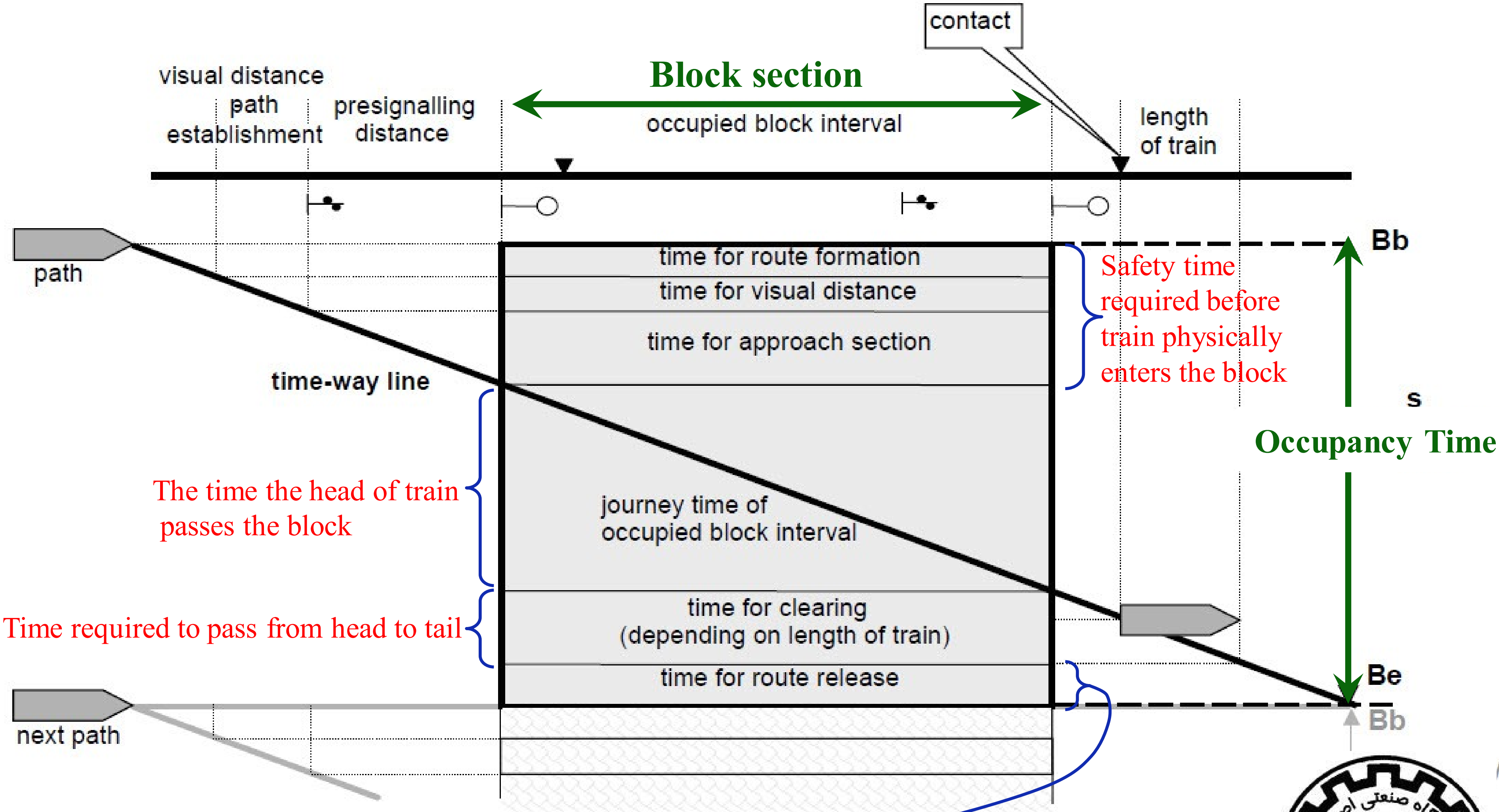
$$\text{Capacity Consumption [\%]} = \frac{\overbrace{\text{Occupancy Time} + \text{Additional Times}^{*}}}{\text{Defined Time Period}} \times 100$$

Occupancy Time:

Total time required for one train to **pass through** a block section

Additional Times:

Any time value added to **secure** operation quality (buffer time, etc.)



s : occupancy time of line section for each train path

Bb : beginning of occupation

Be : end of occupation

s = Be - Bb

Time required for Switching of signals to allow occupancy of next train

No consideration of

Time required for Switching of signals to allow occupancy of next train

Video

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General workflow of the UIC 406 method

Build up infrastructure

↓

Create timetable

↓

Divide railway network into line sections

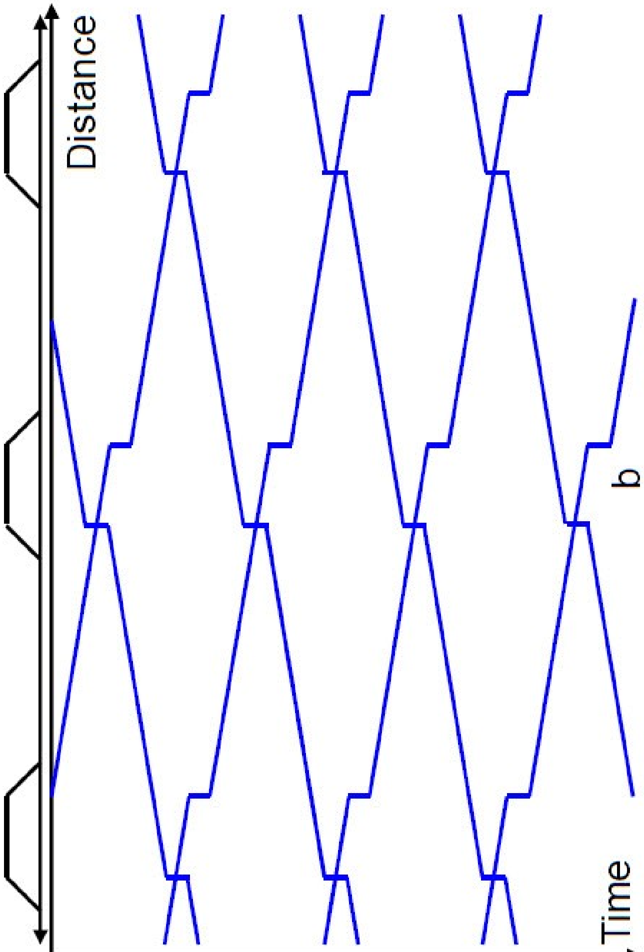
↓

Compress timetables

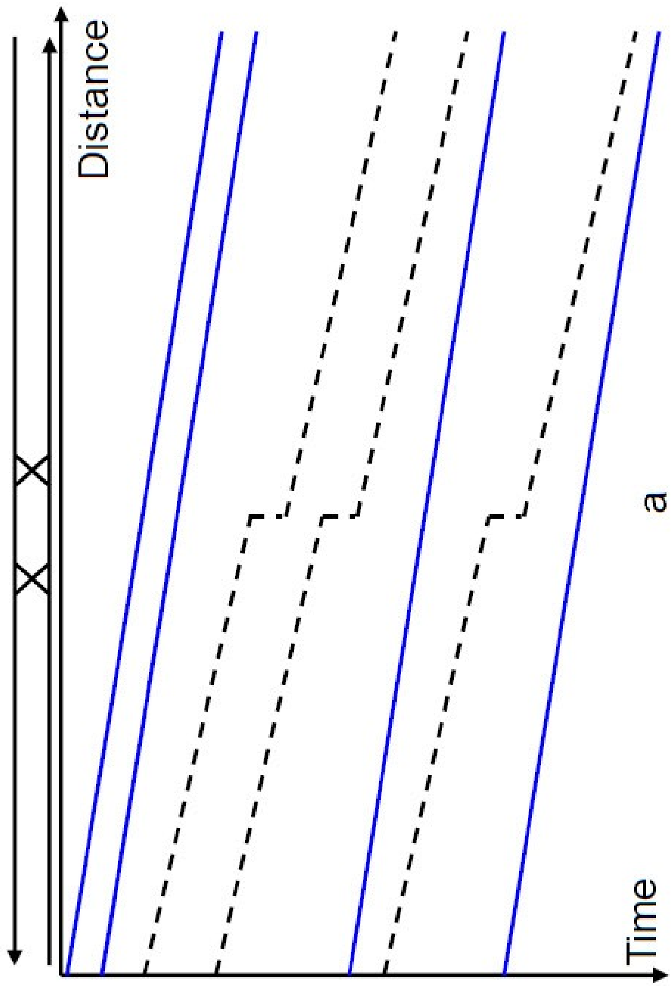
↓

Work out capacity consumption

Typical timetable patterns



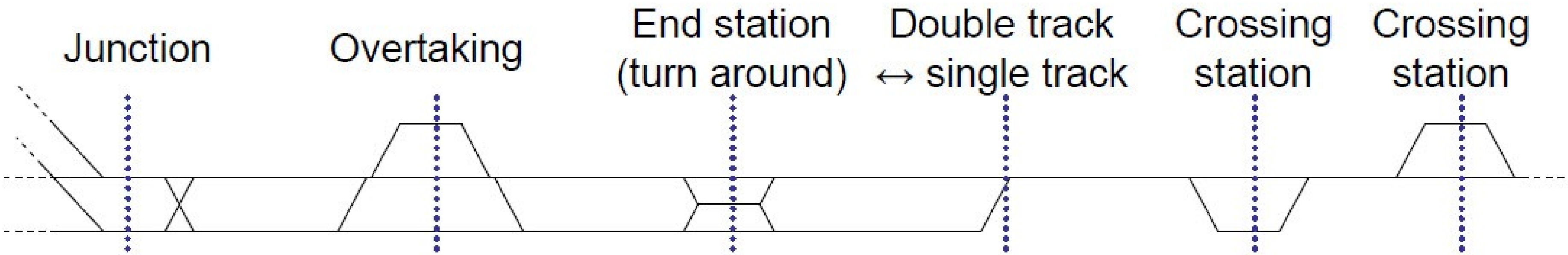
(a) a single track railway line



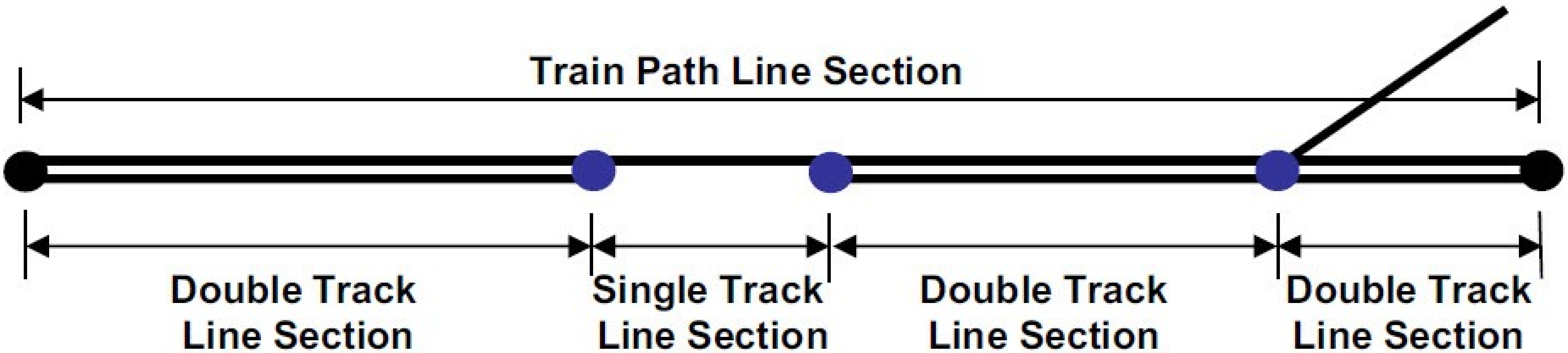
b) a double track railway line in one direction

Landex, 2008

Dividing railway lines into line sections

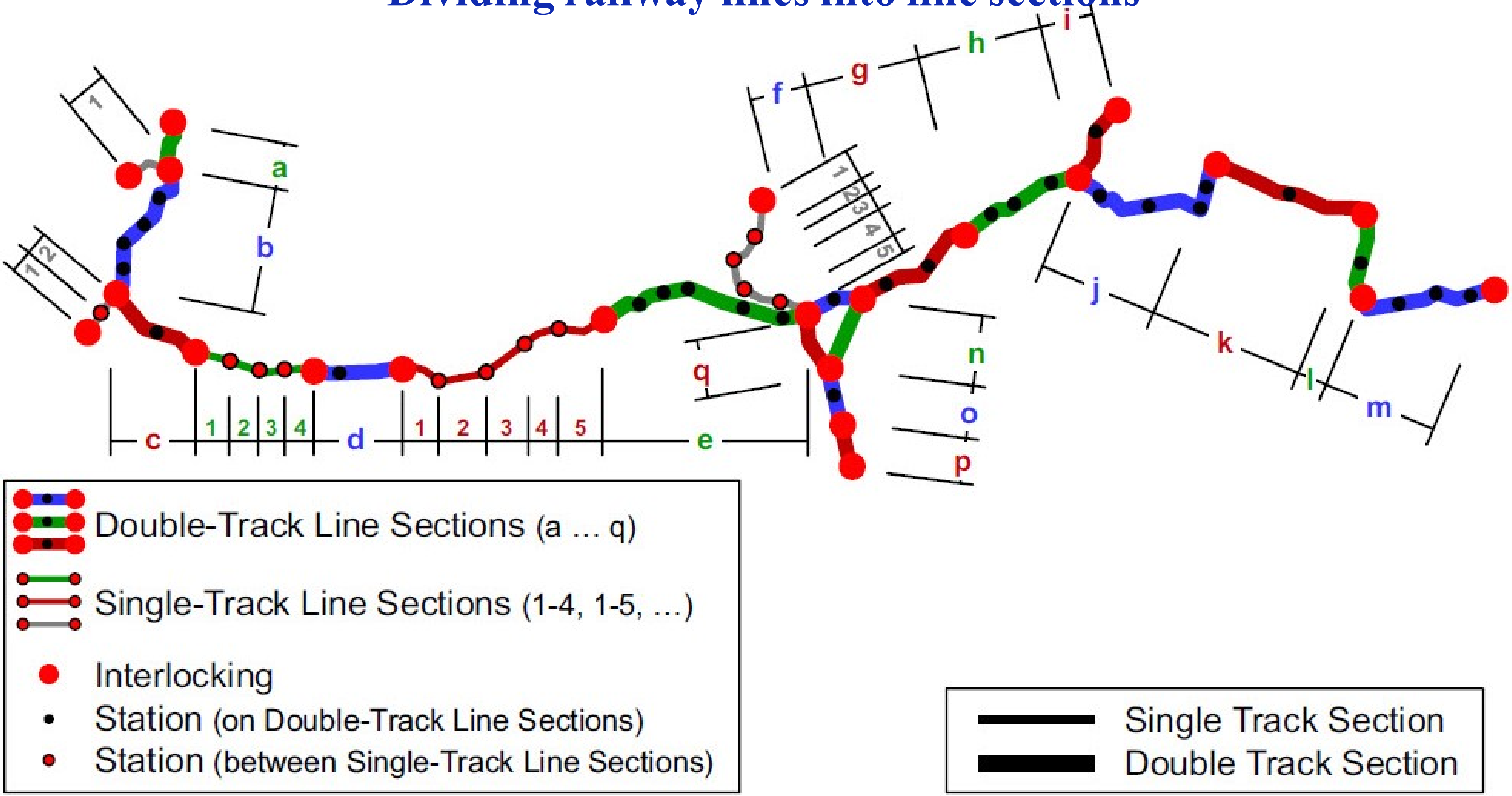


Landex, 2008



UIC 406 (2013)

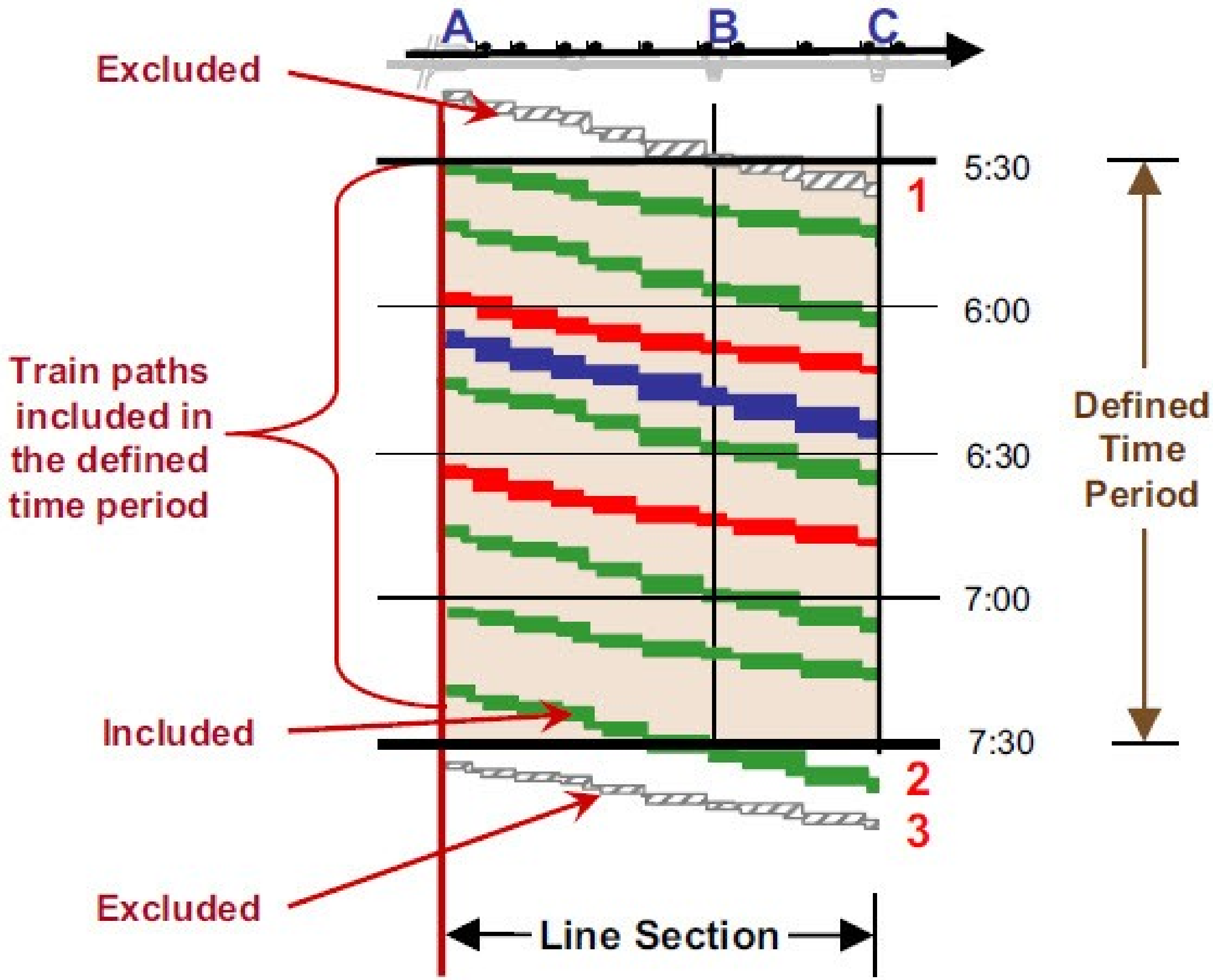
Dividing railway lines into line sections



$$CC_{corridor} = Max\,\{CC_{Block\,1}, CC_{Block\,2}, \ldots, CC_{Block\,n}\}$$

UIC 406 (2013)

Timetable of a line section



Note: Train paths which enter the line section before the beginning or after the termination of the defined time period will be excluded

Compression of timetables

Definition:

For compression purposes, all **single train paths are pushed together** up to the **minimum theoretical headway** according to their timetable order, **without** recommending any **buffer time**.

How to do compression?

- by constructing **graphical** analysis or suitable tools for this case

or

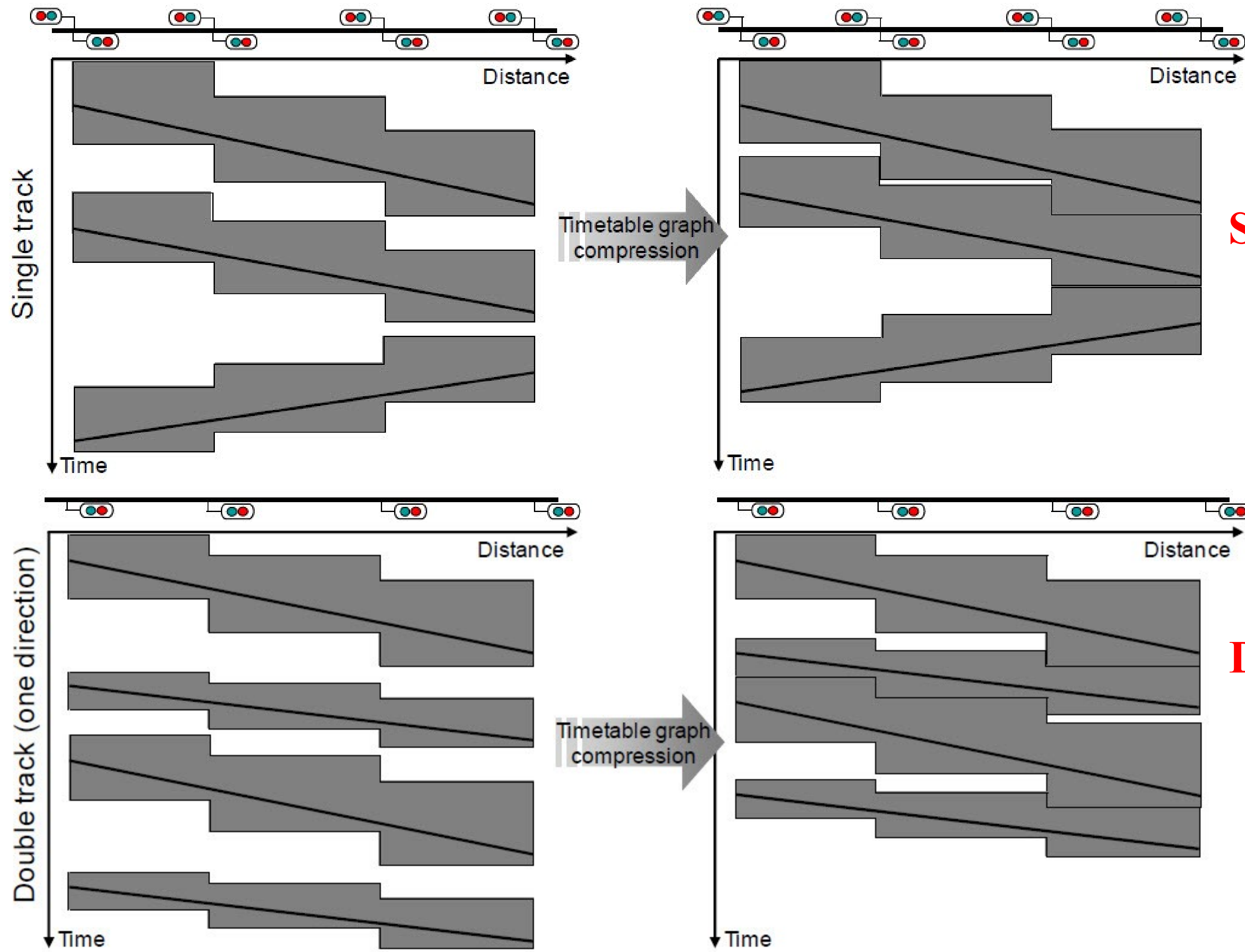
- by **analytical** calculation.

Rules of compression

During the compression process, neither the timetable **running times**, nor the given **overtakings, crossings or stopping times**, may be changed.

UIC 406 (2004)

Compression of timetable



Single-track

Double-track

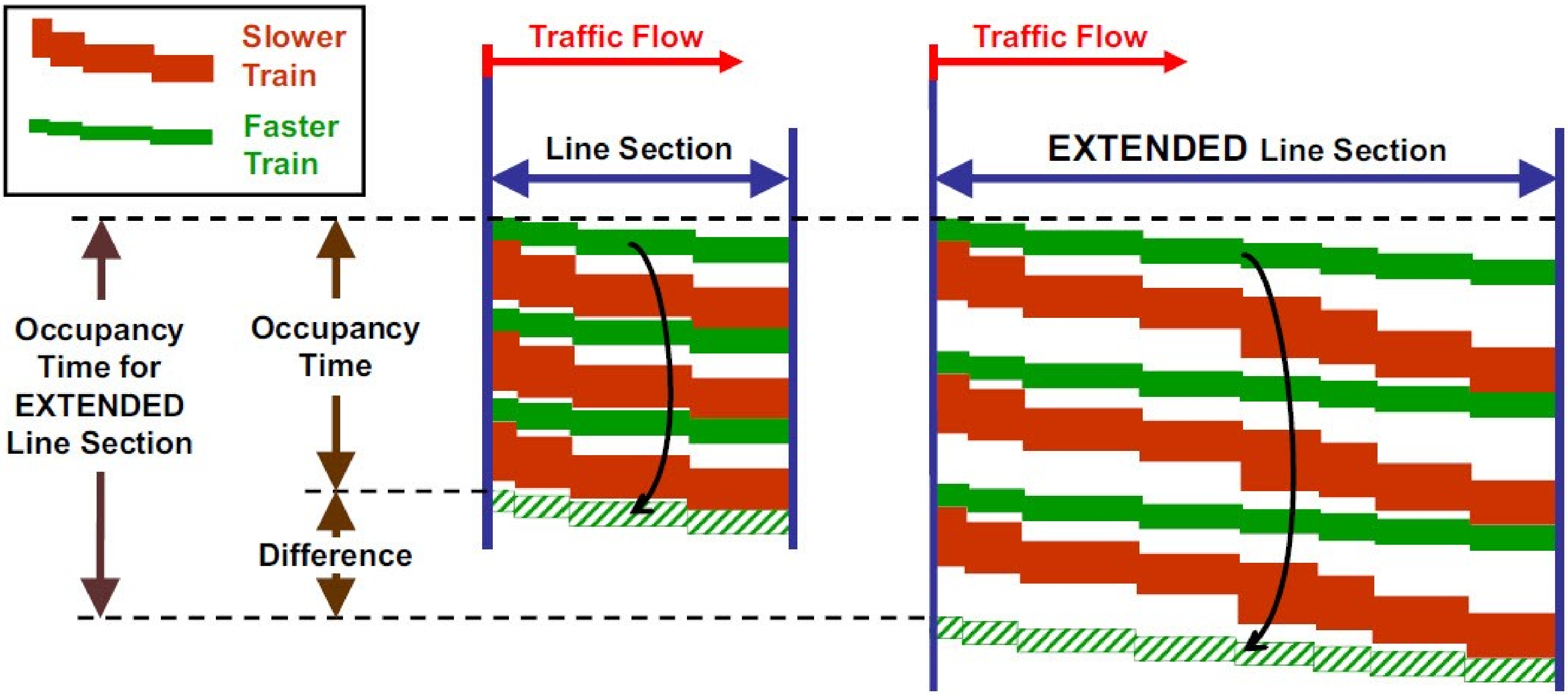
Landex, 2008

Compression of timetable

Capacity consumption is calculated **by compressing** all block sequences along the train paths within a defined timetable to an infrastructure's physical limits.

The time resulting after compression = **Occupancy time**

Compression of timetable



The line section length affects the occupancy time

Calculation of Capacity Consumption

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

Calculation of Capacity Consumption

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

A general recommendation for 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 %

UIC 406 (2013)

Calculation of Capacity Consumption

$$\text{Occupancy Time Rate [\%]} = \frac{\text{Occupancy Time}}{\text{Defined Time Period}} \times 100$$

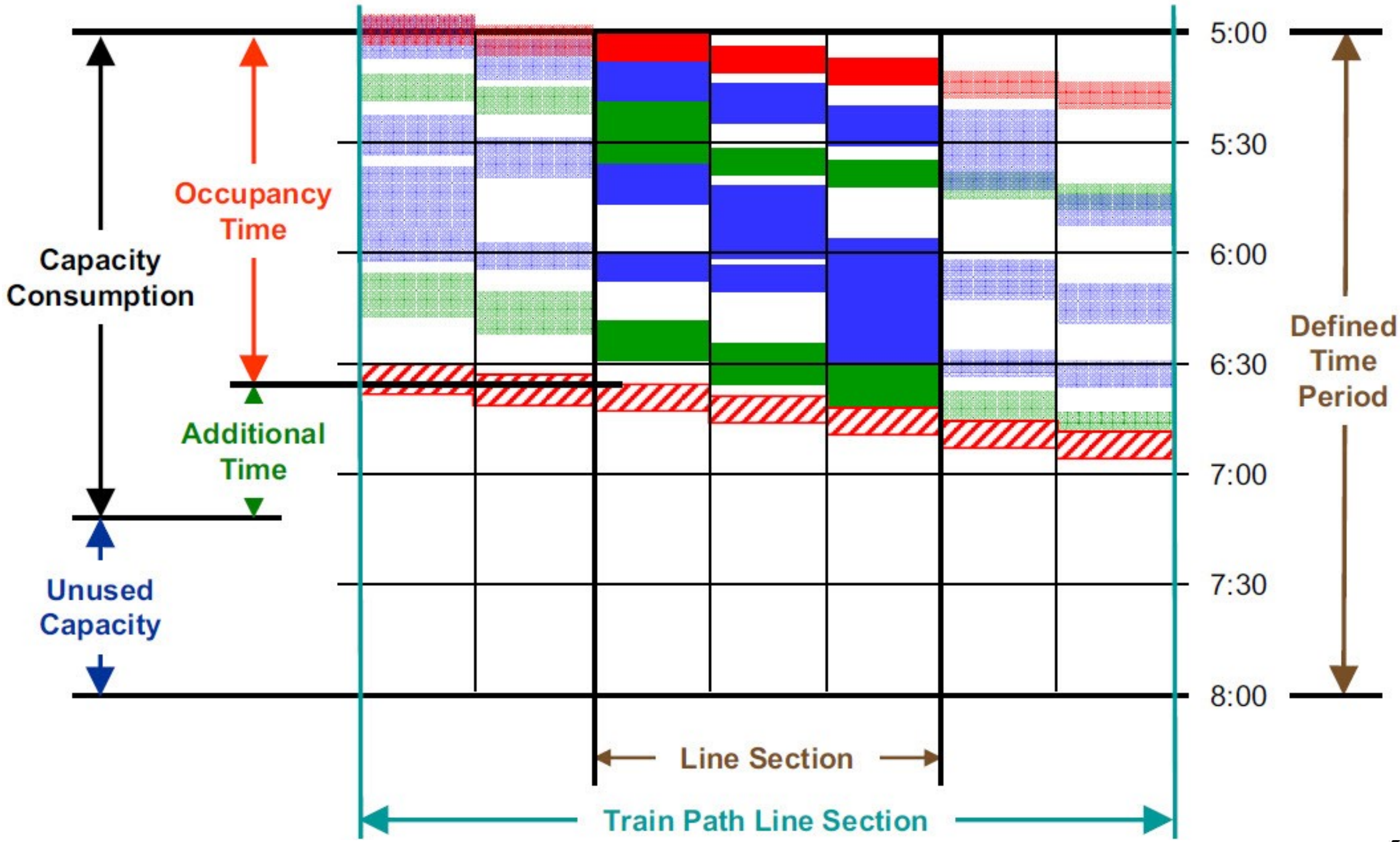
A general recommendation for occupancy time rates

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

* It is exactly the same with the recommended values by UIC406 (2004) for infrastructure occupation

UIC 406 (2013)

Evaluation of Capacity Consumption



C.C of the train path line = maximum { C.C. of all its line sections}

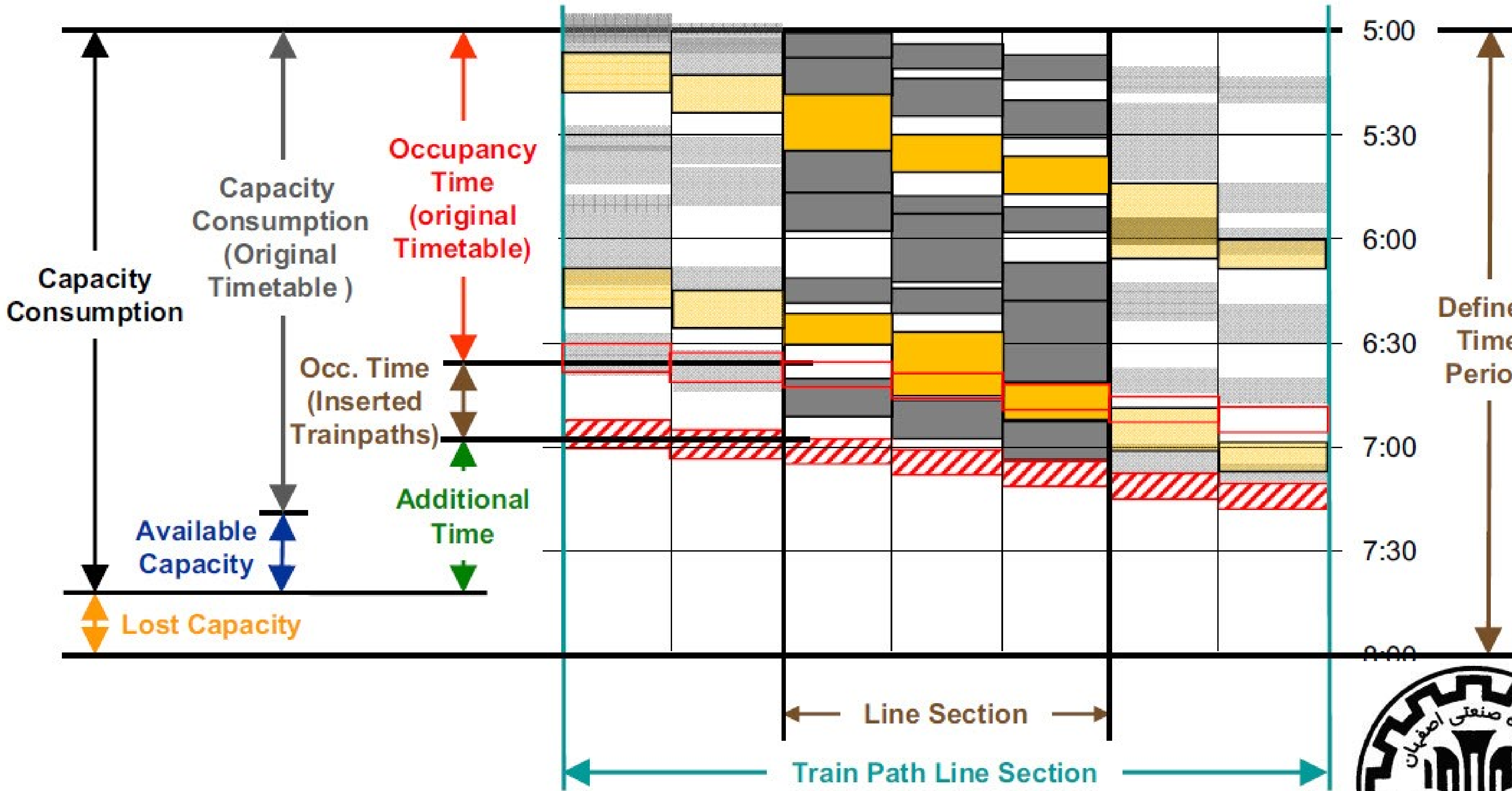
UIC 406 (2013)

Evaluation of Capacity Consumption

- ✓ The recommended workflow process is **to insert or exclude train paths** until capacity consumption has **reached to 100%** (No additional train path can be inserted)
- ✓ By inserting new trains, it is possible to assess capacity consumption and to obtain information on **available and lost capacity**.

UIC 406 (2013)

Evaluation of Capacity Consumption



Available and lost capacity after inserting additional train paths

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