Railway systems and their transition
Lecture 5

Traffic Management Systems

Peter Kummer
EPFL, Autumn Semester 2025
October 14, 2025

Preparatory reading for the lecture.

Introduction to train control, path planning and rail operations and their digitalisation initiatives

You can find it on

moodle

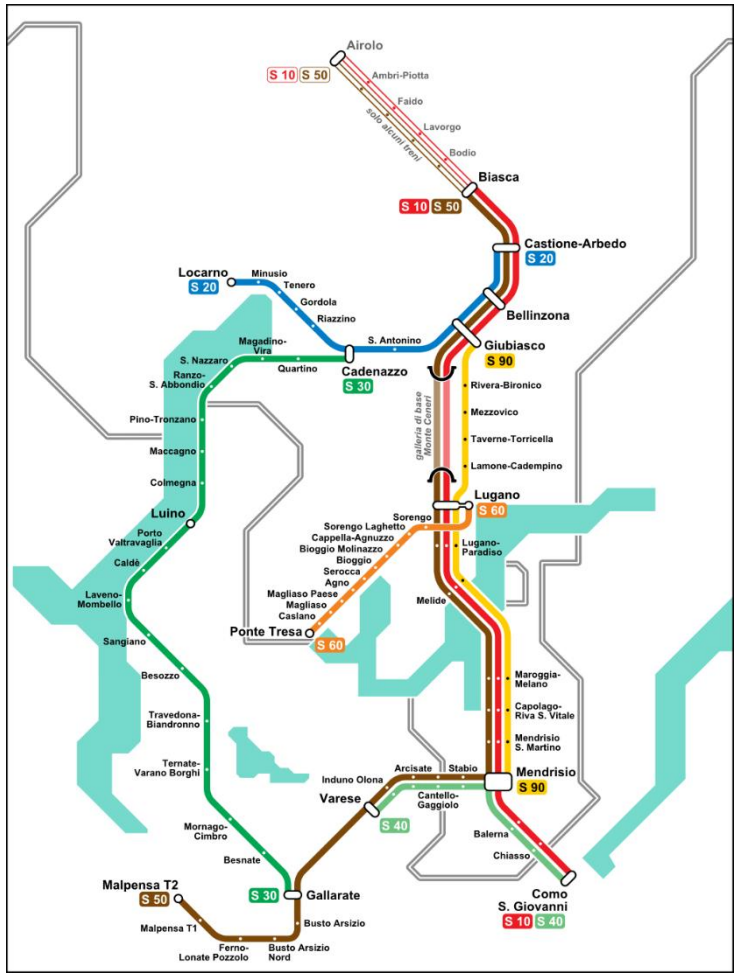
Agenda.

1. Intro
2. Pitch «Case Study» from last time
3. Feedback & Solutions
4. Traffic Management Systems
5. Case Study

Case Study Rolling Stock.

TILO (Treni Regionali Ticino Lombardia) is in need for a new train.

Task description.



Source: Mappa rete celere ticinese - S-Bahn Tessin – Wikipedia

- Setting:
  - You are the project manager(s) of the acquisition project as an employee of the RU TILO.

- Boundary conditions:
  - The trains must be capable of operating the specified services (illustration), in addition to S60 (narrow gauge).

- Tasks:
  - 1. Define **strategic goals** for the acquisition project.
  - 2. **Conceptualise** the new train systematically for the public call for tenders (what do you expect from the manufacturer? What requirements has the train to meet? How many do you need?). Justify your decisions and present your solutions adequately.
  - 3. Identify challenges regarding **infrastructure and interoperability** (relation to week 3).

  - 4. For the motivated: Investigate the rolling stock market **to identify one or more potentially suitable products** that meet your requirements.

Case Study Feedback.

Feedback Peter Kummer and
solutions SBB has chosen to this challenge.

Railway Assets.

Part 03 «Traffic Management Systems».

Railway Assets.
Agenda.

Part 1
«Heavy Assets»

Part 2
«Rolling Stock»

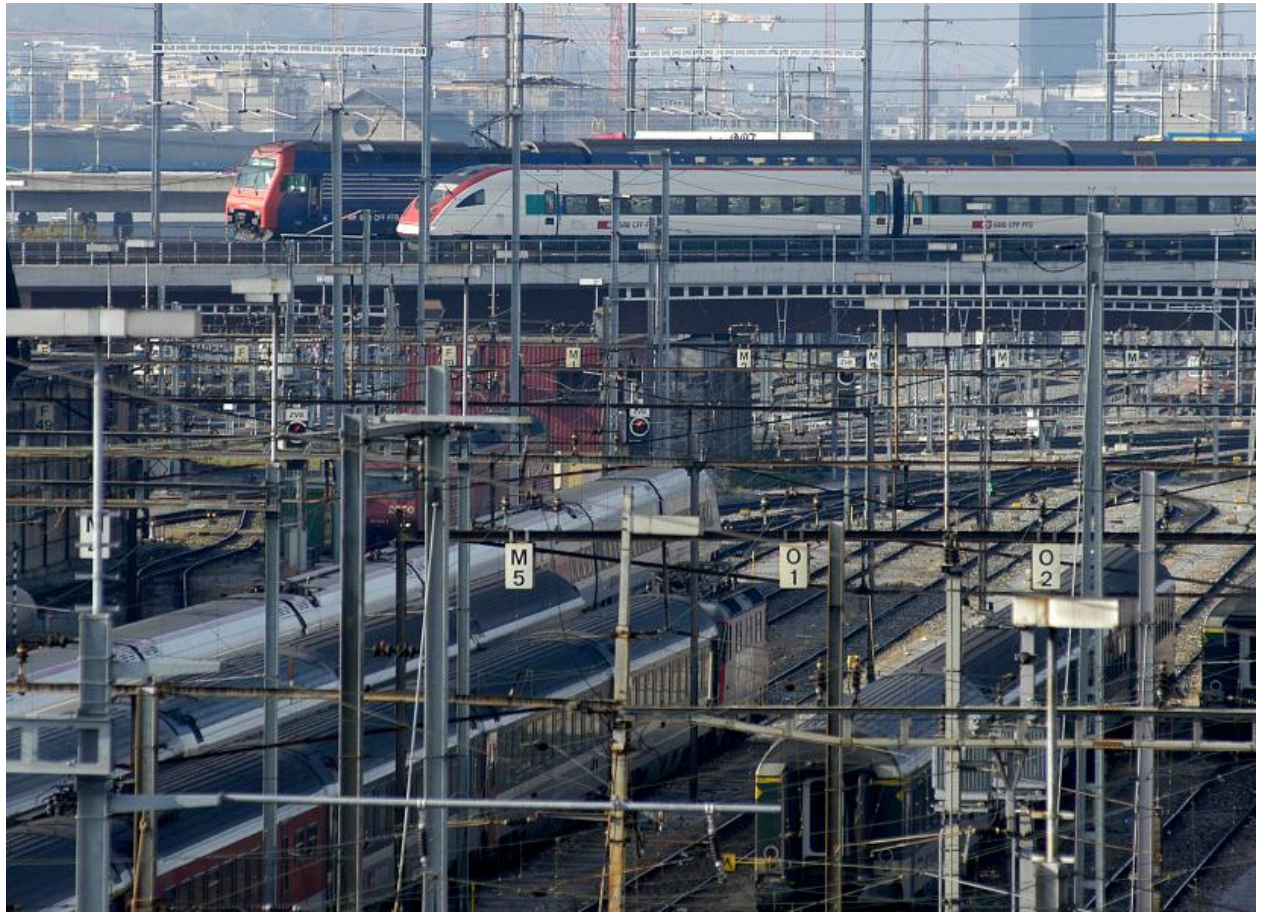
Part 3
«Traffic Management Systems»

Traffic Management Systems.

1. Essential system characteristics
2. Architecture of the system
3. National railway development and its challenge for Europe
4. Improving efficiency through digitalization
5. Outlook

1. Essential System Characteristics.

What are the essential characteristics of the railway system?



Railways

- are track-bound
- use steel wheels on steel rails
- form trains with linked wagons

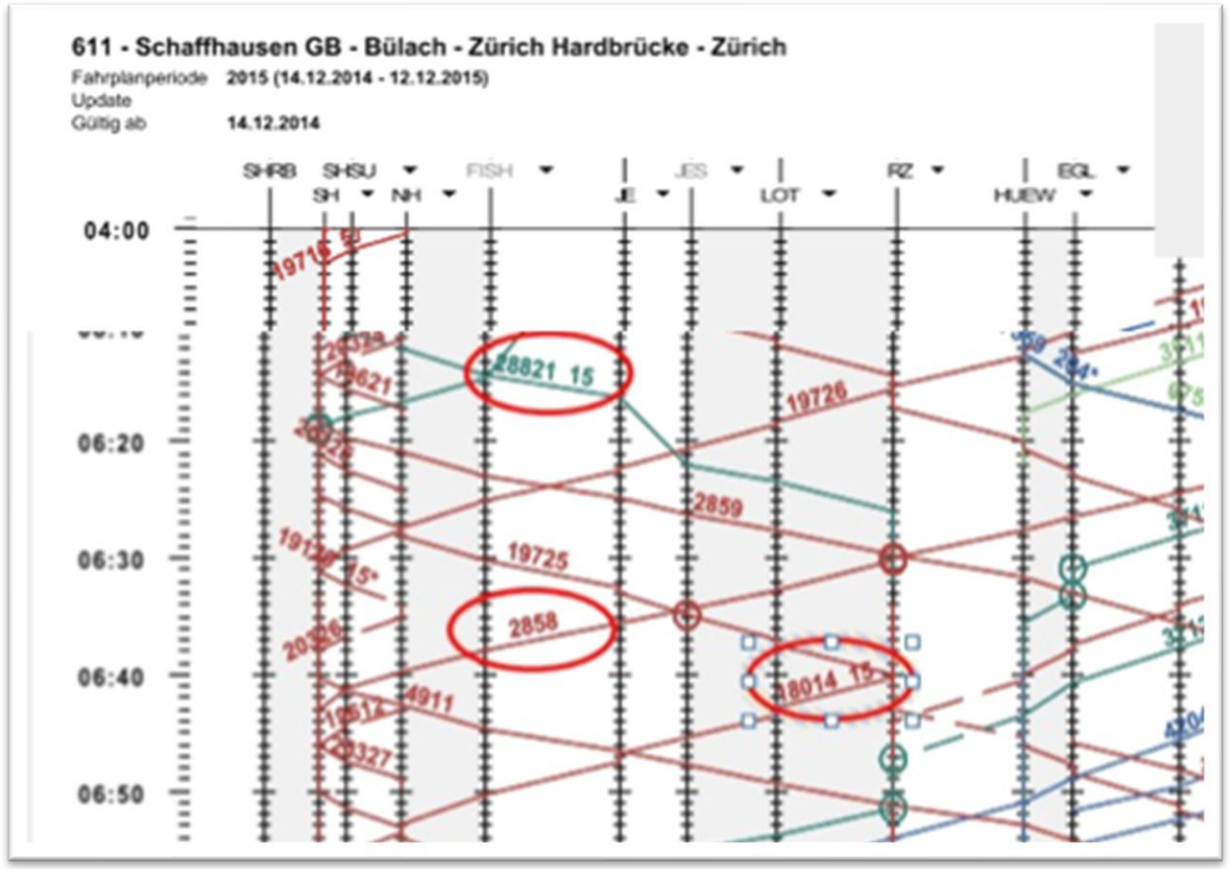
This leads to

- a potential for high capacity
- a potential for high speeds
- high efficiency

Which requires

- high safety standards
- planning processes (timetable)
- systems for traffic control

Timetable.



- Trains operate, unlike individual road traffic, according to a **predefined timetable**.
- Trains run on **paths** (time slots) that must be planned **without conflicts**.
- **Each train is assigned a unique number** used both in technical systems and in communications between train dispatchers and drivers.

Why use a Control Command System?

Safety Comparison.

Risk comparison of selected land transport modes, 2013–2022

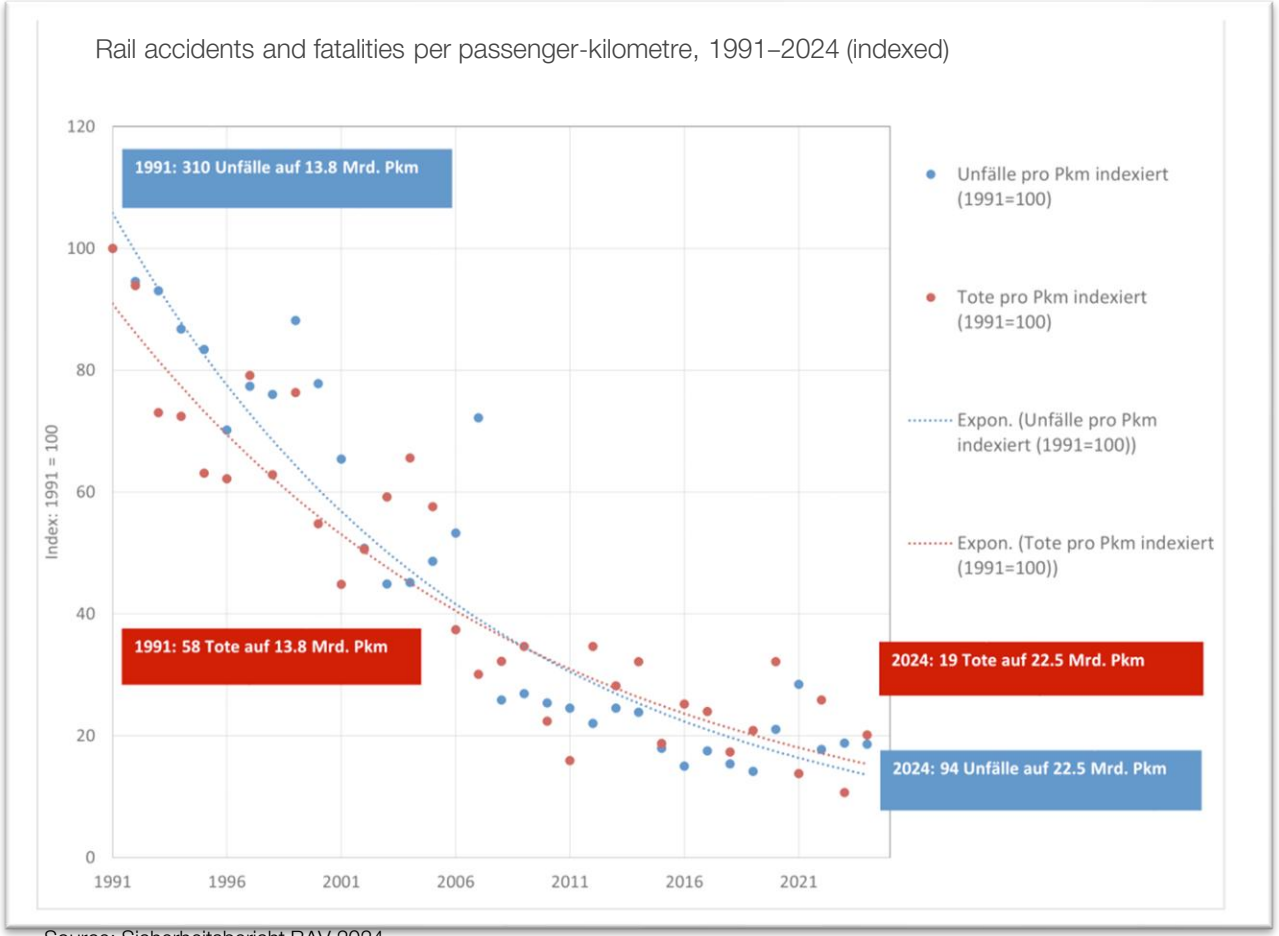
	One fatality per:	Death risk per distance travelled, measured relative to the safest of the compared transport modes, railway (=1)
Railway	190,86 bn passenger-km	1 time
Passenger car	1,13 bn passenger-km	169 times
Bicycle (excl. e-bike)	0,10 bn passenger-km	1985 times
Motorcycle	0,04 bn passenger-km	4732 times

Source: 11 Mobilität und Verkehr, Die Schweiz in Zahlen – Statistisches Jahrbuch 2024, BFS

The safety level of public transport is very high.
In recent decades, public transport has even become safer by a factor of two to three. Compared to other modes of transport, the railways are above average safe.

→ However, the **high level of safety of the railways is not system-related, but implemented by means of technical aids**.

Development of safety.

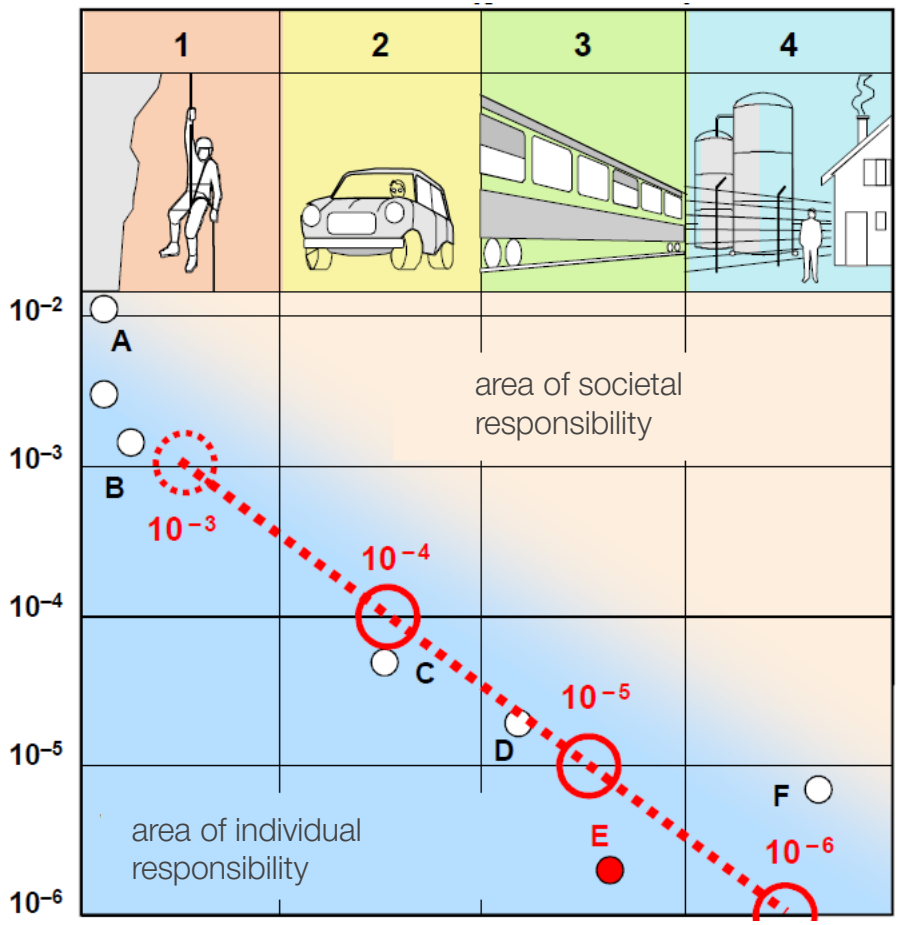


Source: Sicherheitsbericht BAV 2024

– Positive development: Keeping safety high with rapidly growing traffic

Risk acceptance.

The acceptance of the risks cannot be calculated.



Source: Hanspeter Schlatter, SBB Infrastructure

Individual risk per year

A Drug use
B Glider flying
C Car accident (driver)
D Car accident (passenger)
E Railway Passenger
F Apartment fire (toddler)

Railway characteristics.

Large kinetic energy can cause major damage.

Side collision Neuhausen, 10.01.2013

Source: KaPo SH, Plutowiki

Large masses

some 100 t, cargo over 1,000 t

High speeds

Cargo 100km/h, passenger trains up to 200km/h

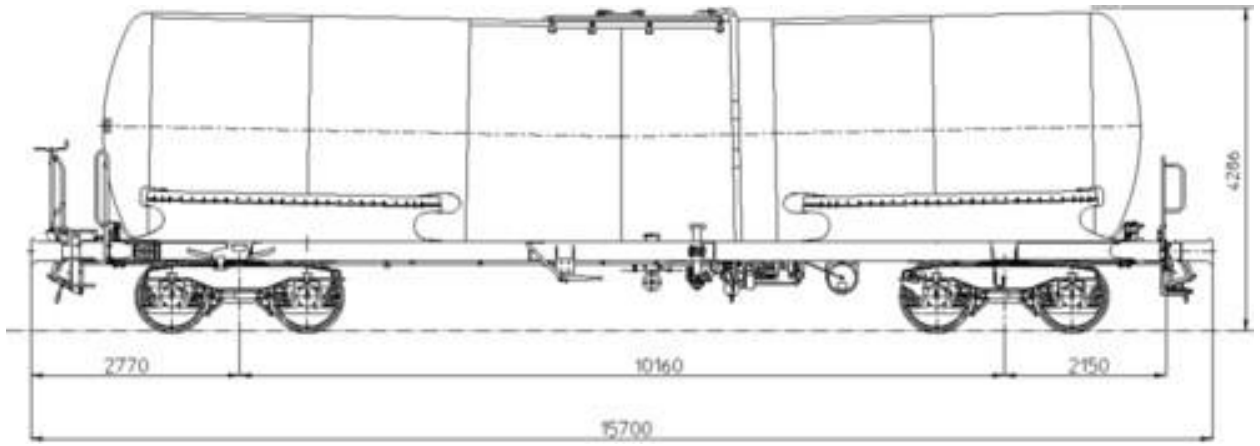
Kinetic energy

Freight train, 100 km/h, 1,000 t: 107 kWh free fall from a height of 40 m(!)

Loading density.

SBB Passenger Transport RABe 511 (KISS)

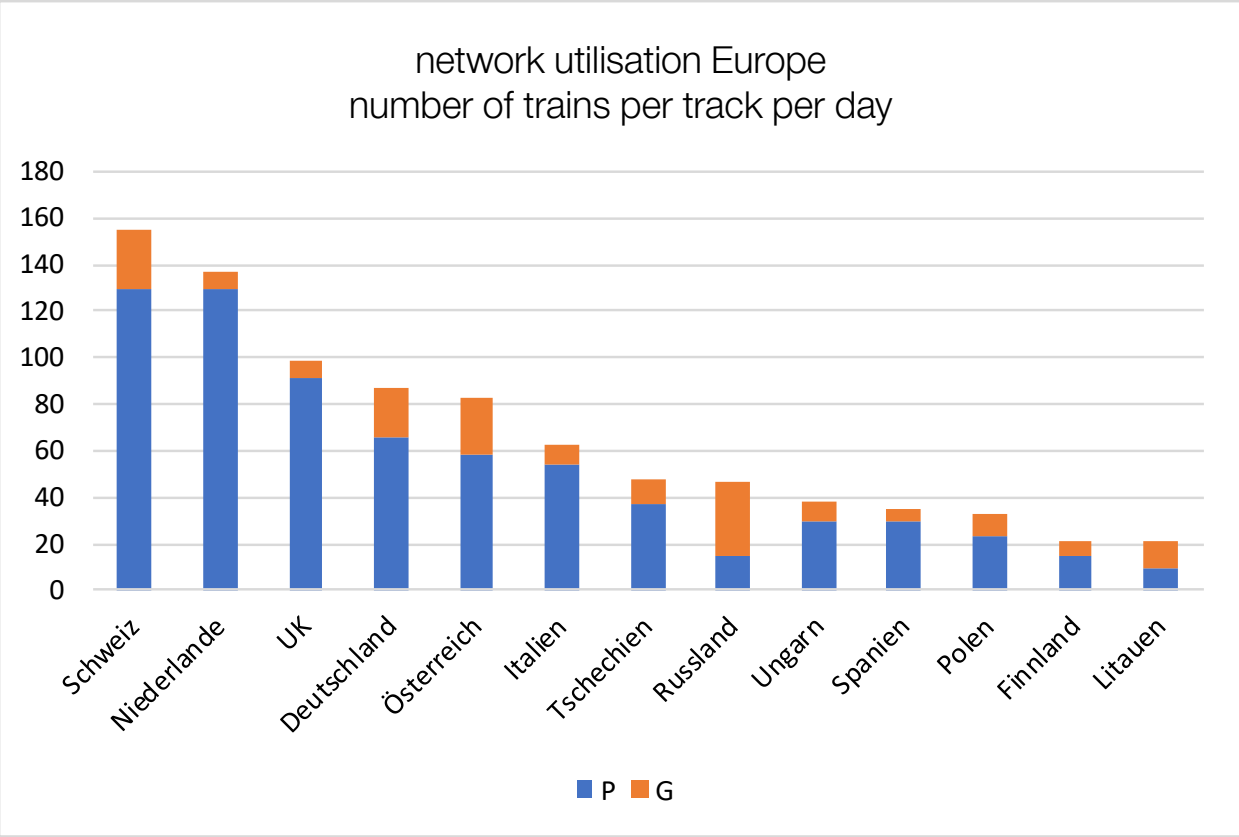
- 535 seats
- maximum 1373 travellers
- 150 m long
- > 9 persons / m



KESSELWAGEN BTAN 95.4-1 RID

- Load up to 72t
- Volume up to 95 m^3
- Length 15.7m

High network utilisation.



Source: VöV, Fakten und Argumente ÖV CH 2018/19

– Switzerland already has a **very heavily used network**. The **denser the traffic, the higher the probability of an accident**, and the greater the potential for many people to be affected by an incident.

Safety

Article 17, paragraph 4 of the Swiss Railways Act (EBG) requires:

'Railway undertakings shall be responsible for the safe operation of railway installations and rolling stock within the framework of the regulations.
'

Article 10 of the Swiss Railway Ordinance (EBV) requires

'1 Railway undertakings shall be responsible for the proper planning, construction, safe operation and maintenance of structures, installations and rolling stock.

2 They must adapt existing buildings, installations and vehicles to new findings, changed framework conditions or amended regulations, insofar as this is absolutely necessary for safety."

According to IEC 61 508, safety is defined as "freedom from unacceptable risks".

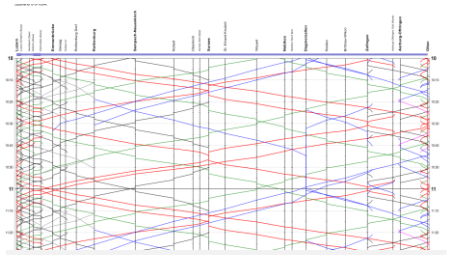
Risk is defined as the product of the magnitude of harm and the probability of occurrence of a specific event (loss event, hazard).

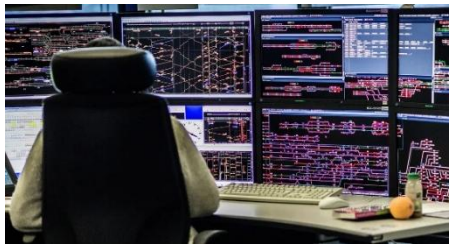
2. Architecture of the System.

The overall system for planning and controlling railway traffic.

Structured in 4 essential architectural layers.

Planning	Annual and daily timetabling	Centralized planning offices
		IP Network
Dispatching	Regulating traffic and fixing disturbances	4 operations centres
		Private Network
Safety layer / Interlocking	Ensuring safe movements on the tracks	100s of interlocking
		Wiring
Field elements	Safely executing movements on the tracks	1000s of signals, switches, trains

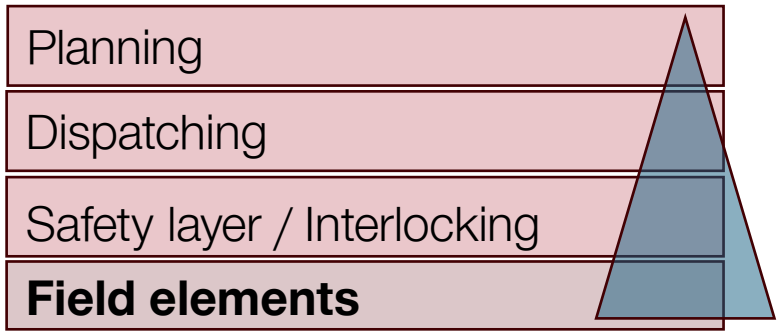


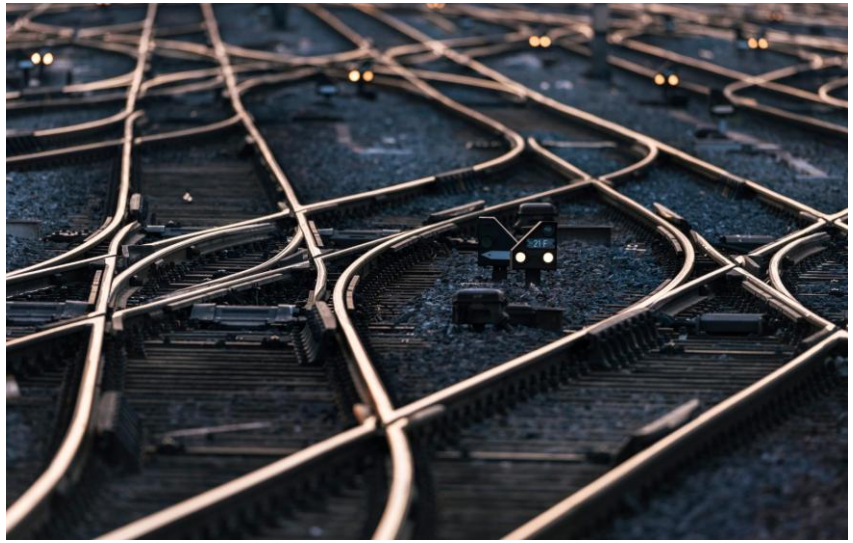


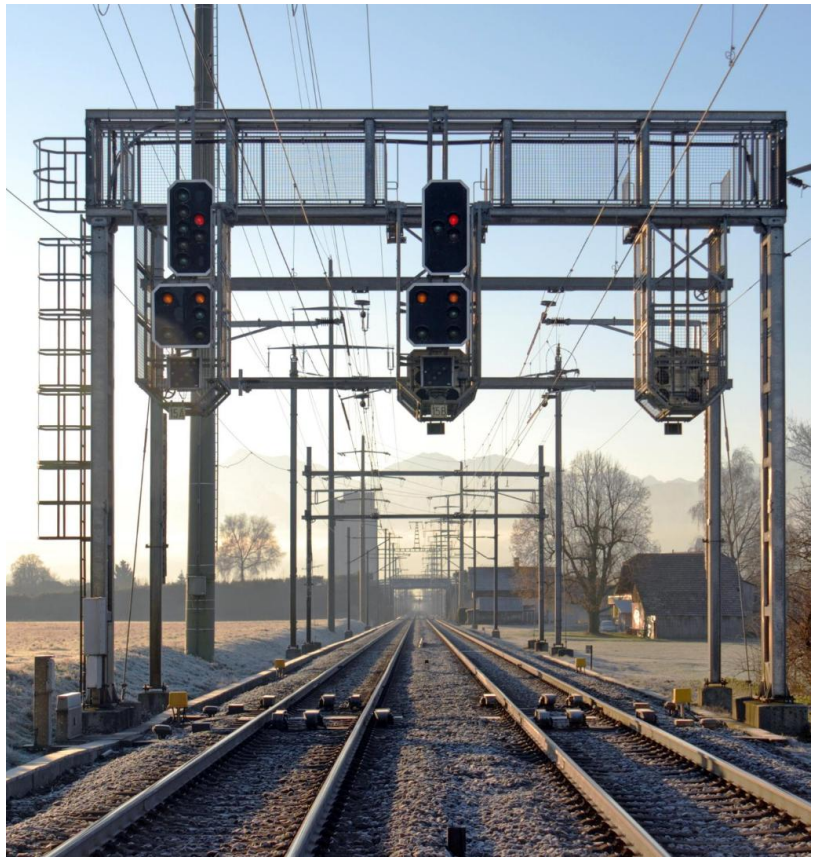
- The 4 layers are essential for mastering the complexity of the overall system.
- Each layer has clearly defined responsibilities.
- From top to bottom we have:
  - Increased safety responsibility
  - More distribution, less centralisation
  - More real-time execution, less advanced planning

Field layer: contains the most important control elements.

«On the track» are switches, light signals and track occupancy devices.

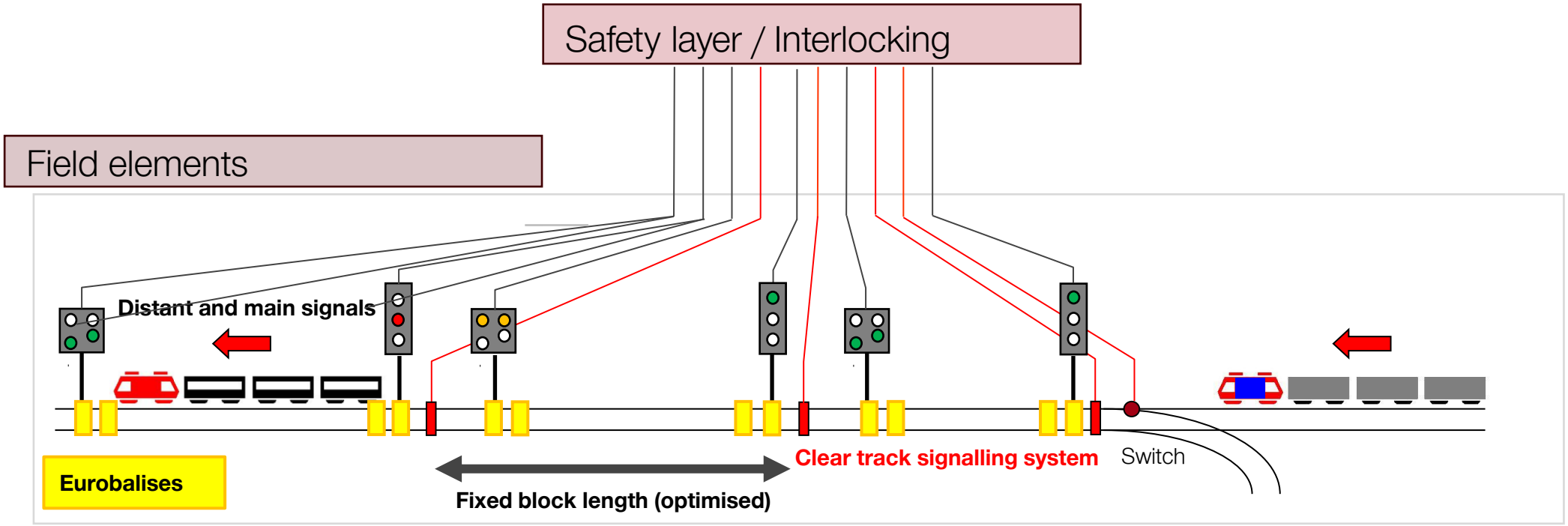






- **Switches** (a.k.a. points) are the only way for a train to change tracks.
- **Light signals** are essential for safe circulation. Light signals **are combined** with train protection systems, which stop a train, if the train driver disregards a signal.
- **Track occupancy** devices tell the interlockings, whether a section of the track is occupied or clear.

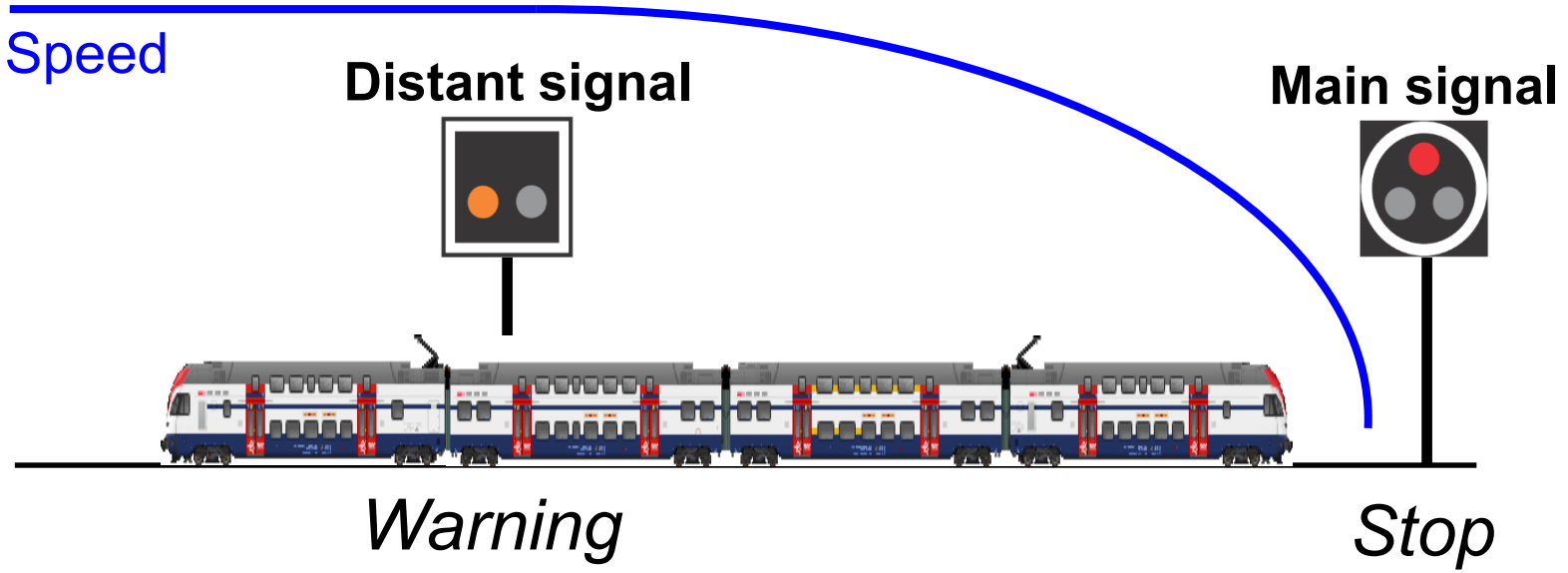
Very numerous field elements.



SBB (2024): 12700 switches, 35400 signals,
1100 level crossings, 17800 sets of balise (two each), 34800 axle counters/insulated rail joints (clear track signalling system), ..

Enormous braking distances.

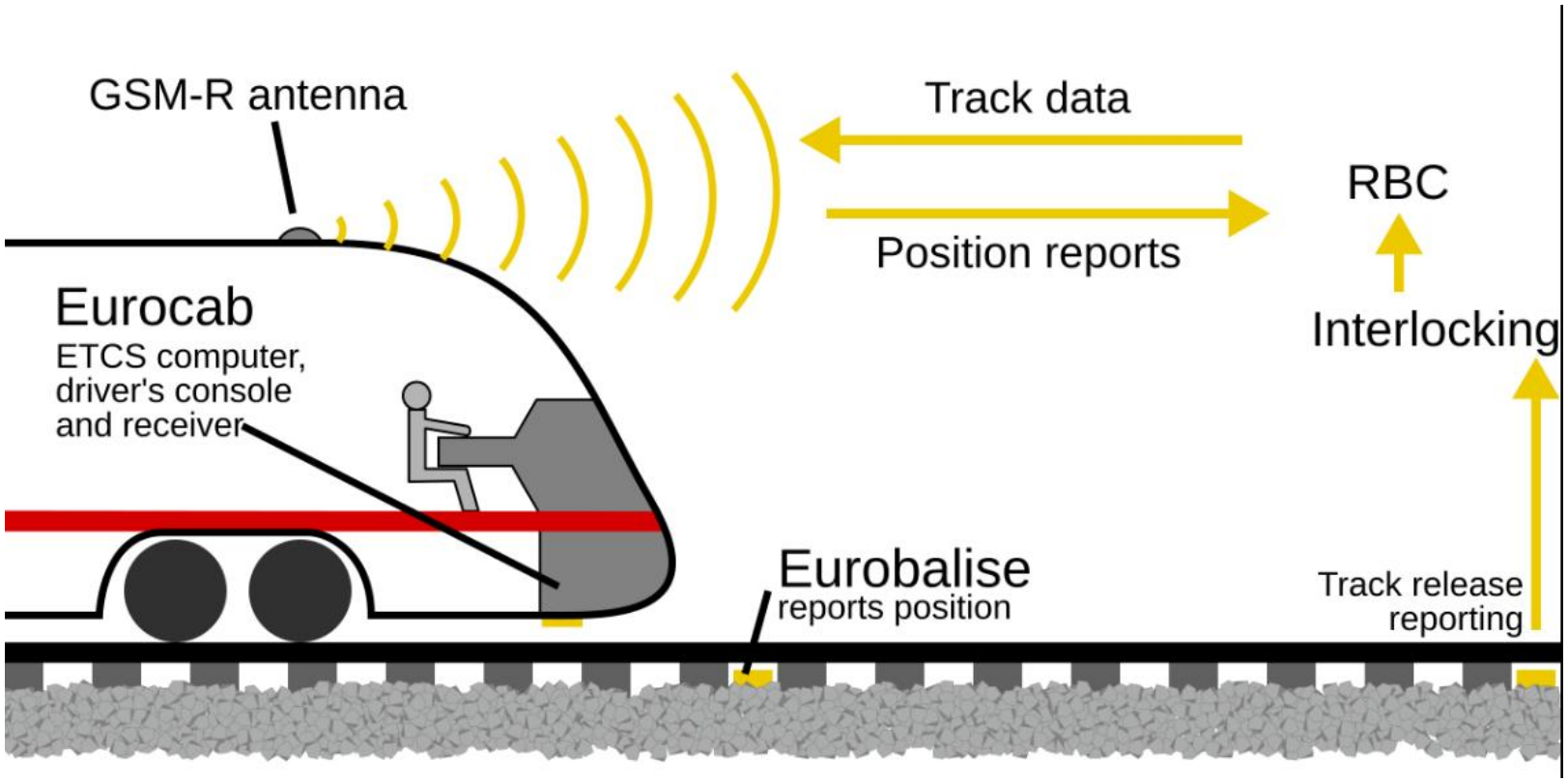
Require «advanced» or «distant» signal to announce the state of the real signal.



- A train must be able to stop between the distant signal and the main signal.
- The signal spacing determines the permitted speed.
- Depending on braking performance, trains may be able to travel at different speeds.

A modern alternative to light signals.

Communication based train control systems like ETCS.



- The train **detects** a balise (a coded tag) in the tracks
- The train **reports** the balise by radio to the interlocking
- The interlocking knows where the train is
- Based on the rules in the interlocking, the interlocking sends a «**moving authority**» (e.g. you may advance another 850m») by radio to the train
- The **on-board computer** displays the moving authority to the driver and supervises the movement.

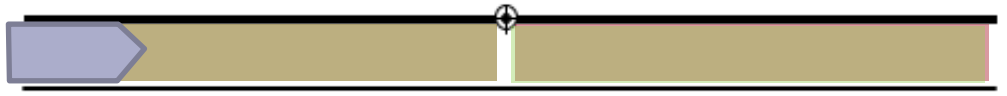
How do we know that a track is occupied or clear?

Currently there are 2 types of track occupancy devices

To ensure safety in the control of train traffic, the signal box must know the positions of trains at all times. Clear track signalling systems are used for this purpose. In addition, train positions are used in the higher-level control systems of operations centres for traffic management.

Two principles are used today for the clear track signalling system:

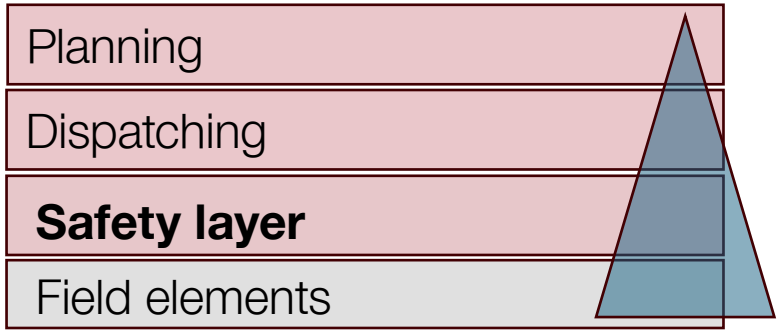
1) Track circuit

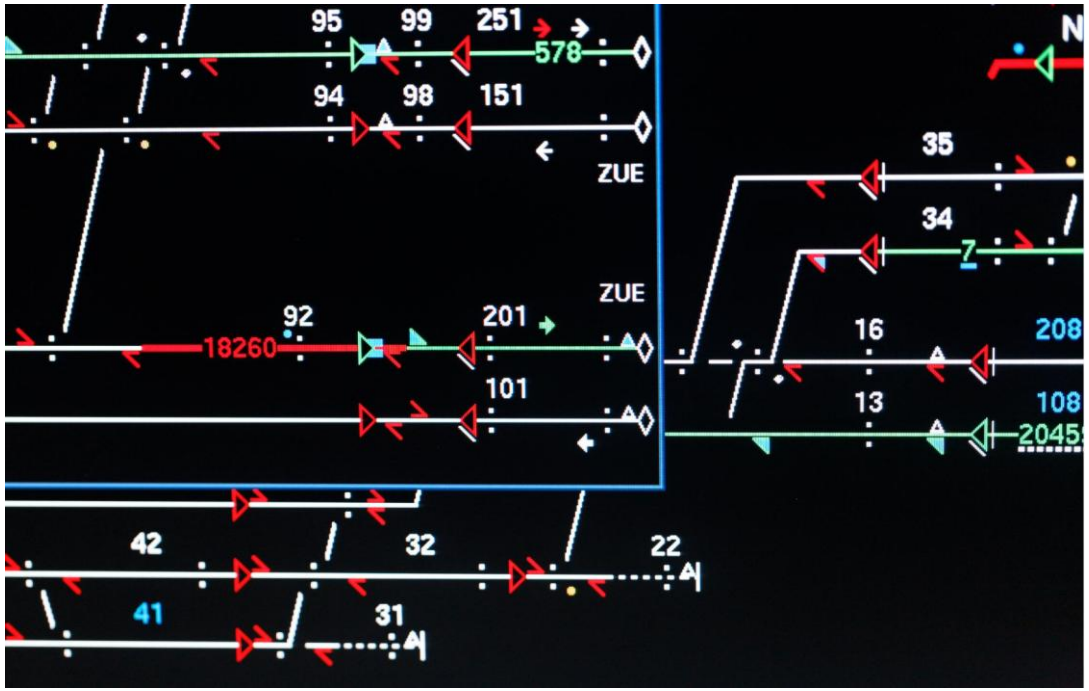


2) Axle counter

Safety layer with the interlockings (a.k.a. signal box).

Ensure that two trains can’t occupy the same spot and collide.

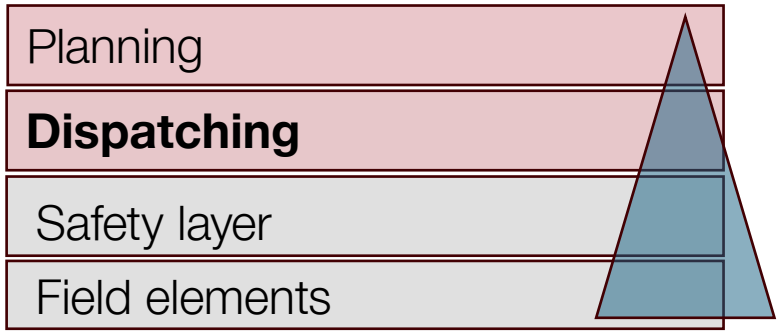


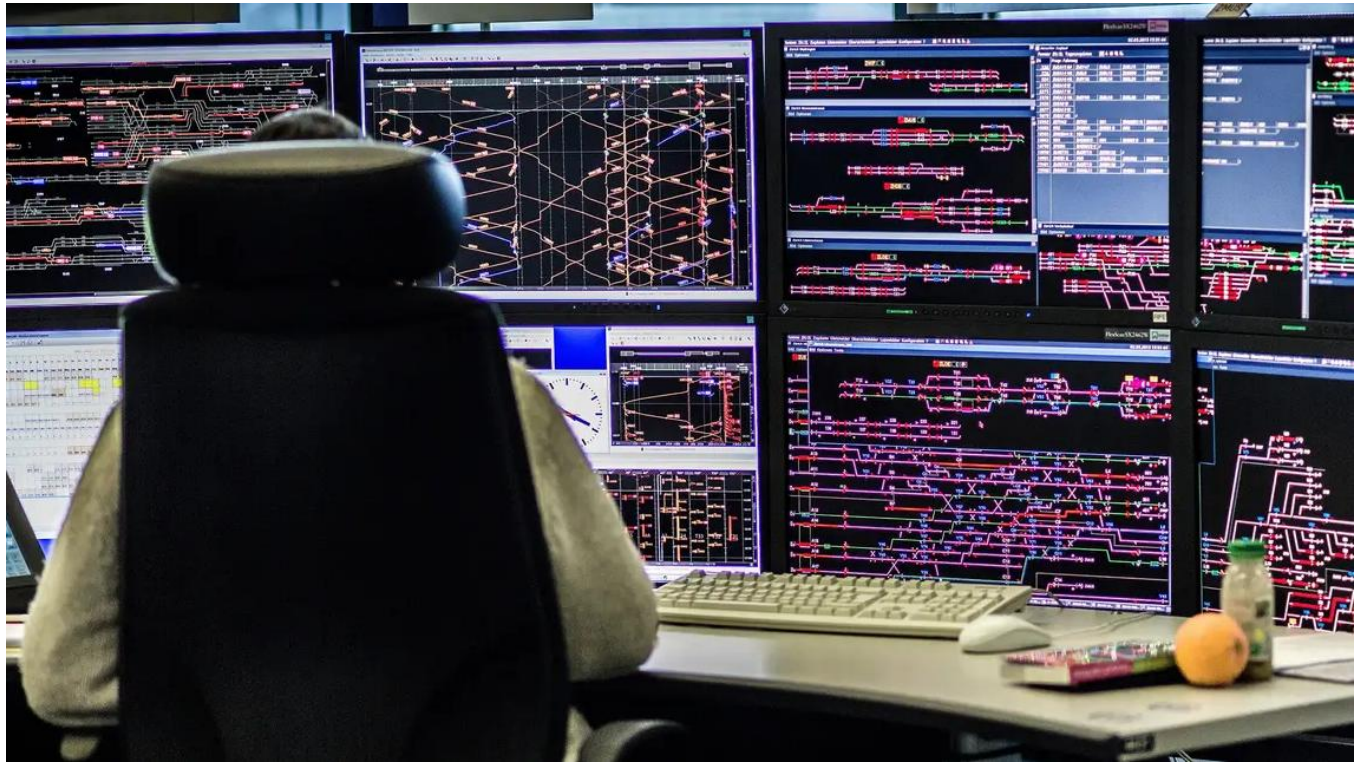


- **Interlockings control a station** or a certain sector
- Based on known occupations, the interlockings control the position of **switches and the light signals to ensure no collisions are possible**
- The **interlockings are the key element of safe railway operations**
- Interlockings must adhere to the **highest safety standards**

Dispatching Layer:

«Produces» the timetable and handles exceptions.





Dispatching is performed **in 4 operations** centres in Switzerland
Consists of **800 dispatchers covering 7x24 shifts**
Main activities in dispatching are

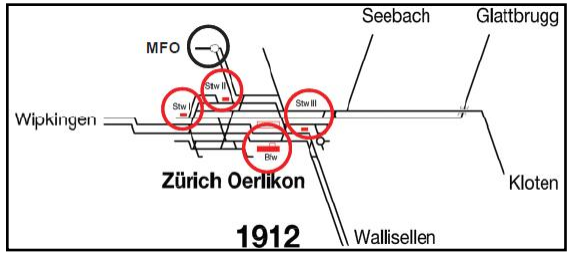
- ensure **execution of the timetable according to plan**
- **Handle disturbances to get back to plan**
- **Handle short-term requests not in the plan**

Main functions of the supporting systems are

- **Optimise capacity**
  Real-time optimisation of the production target
- **Instruct the interlockings**
- Provide a **country-wide overview** of railway traffic and forecasts
- **Provide data to assist drivers** (speed recommendations)

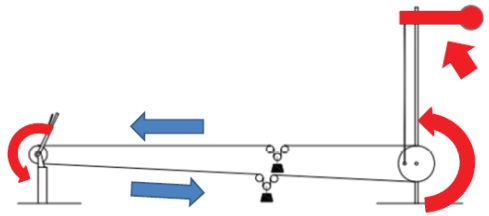
Development of signal operation using the example of Oerlikon.

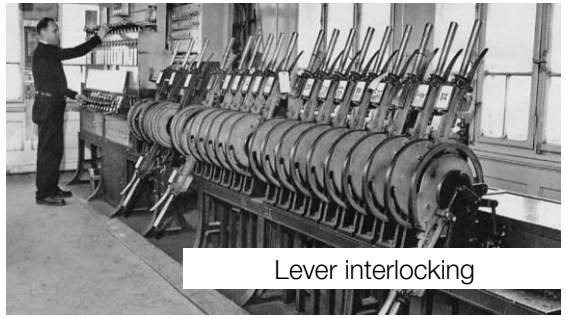
1912



130 trains per day

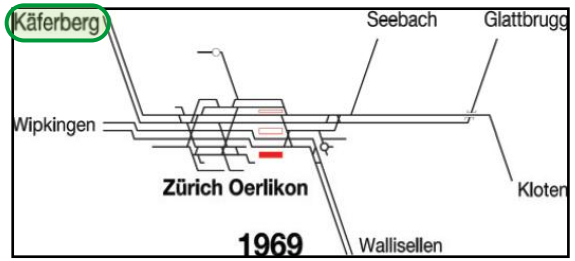
Double wire pull



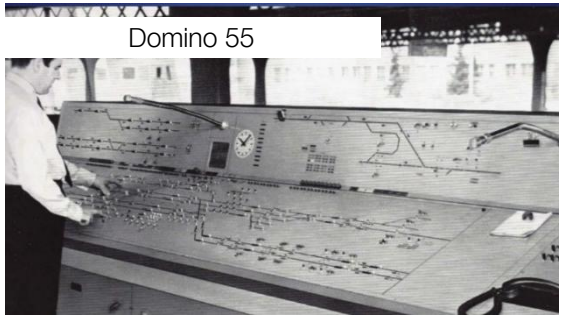


Lever interlocking

1969



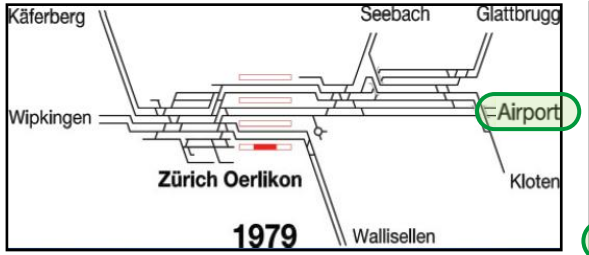
370 trains per day



Domino 55

Regional train monitoring

1979

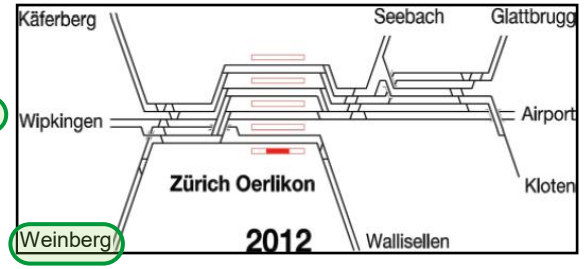


490 trains per day

Domino 67

Zurich Operations Control Centre

2012

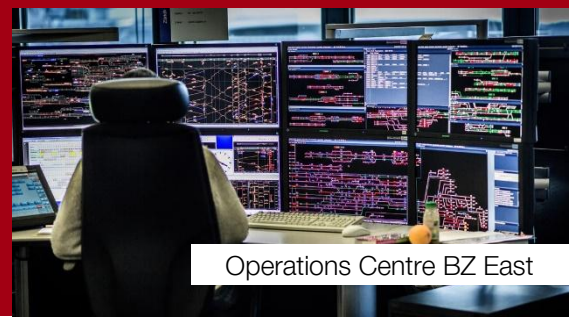


880 trains per day

Command room Oerlikon

Seit 2015

1070 trains per day (2023)

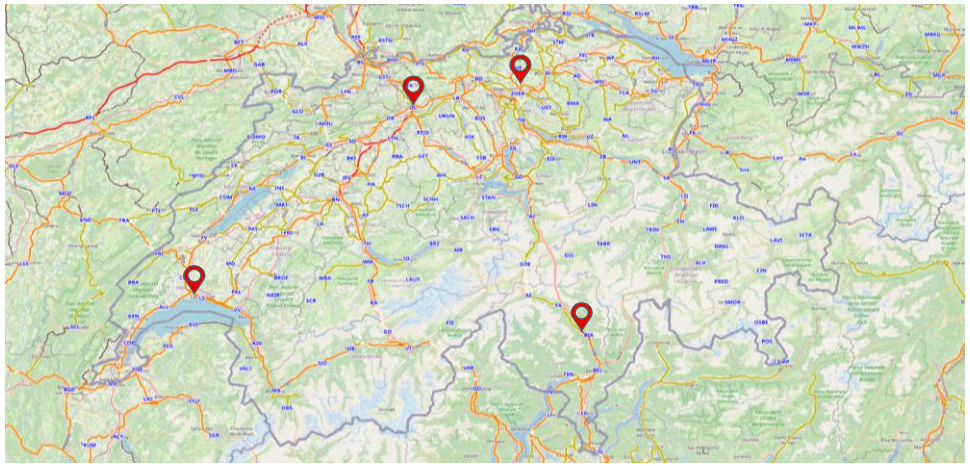


Operations Centre BZ East

Source: 100 Jahre Fortschritt in der Eisenbahnsignaltechnik (Stalder / Wägli, SER 6/2013)
ANABEL (DfA Reports Abfrage, Zugzahlen 2023)

Production Yesterday and Today.

Transitioning from decentralised dispatching to a centralised system with four main train control centres.



1980

- Approximately **600 local dispatchers** at every major station manage operations.
- Introduction of the first remote control systems to manage multiple stations from one location.

2007

- Centralization and introduction of train control centres.
- Only 25 remote control centres in operation.

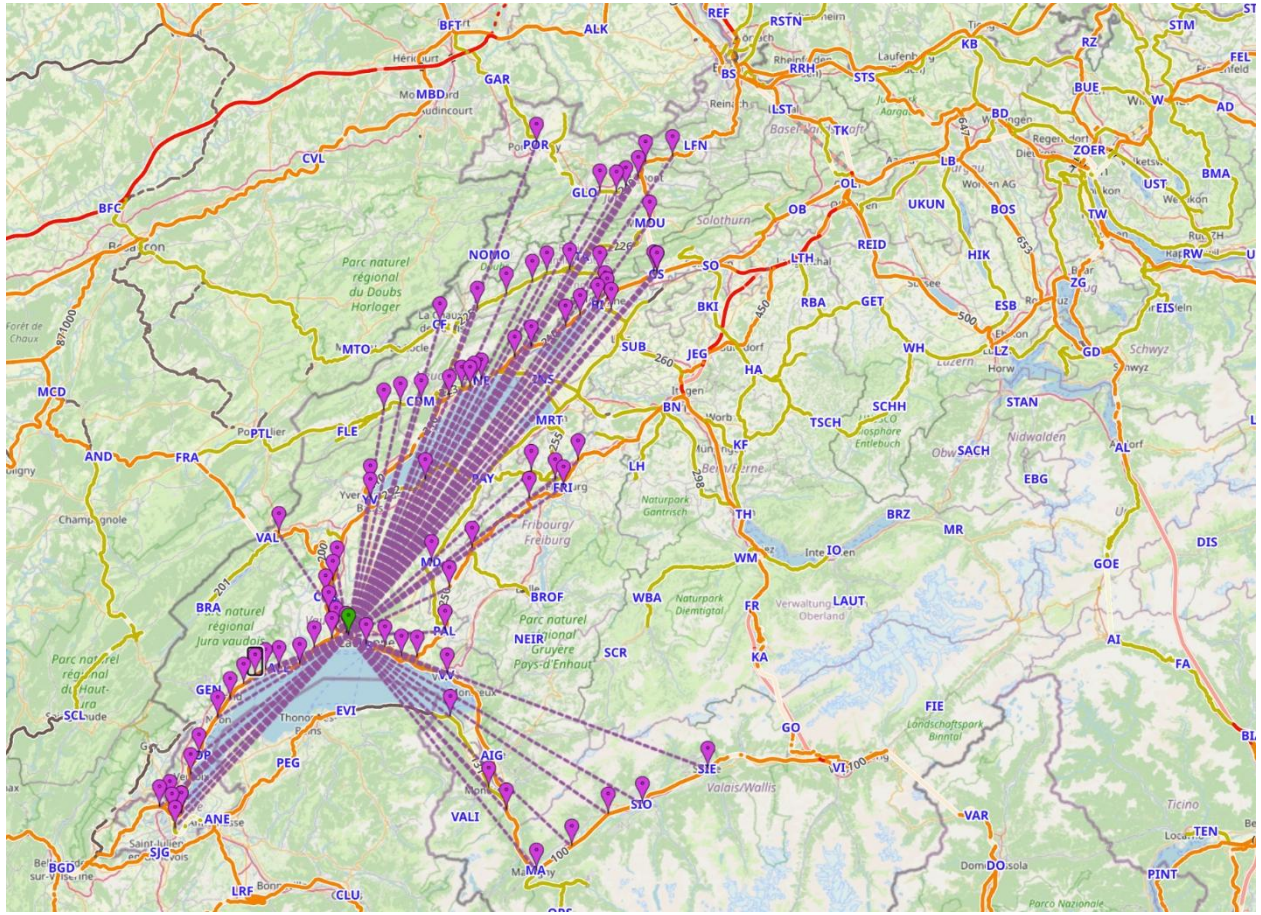
2017

- **Four state-of-the-art train control centres for the entire network.**

Source: stellwerke.info

Production Yesterday and Today.

Transitioning from decentralised dispatching to a centralised system with four main train control centres.



Overseeing the network of signal boxes

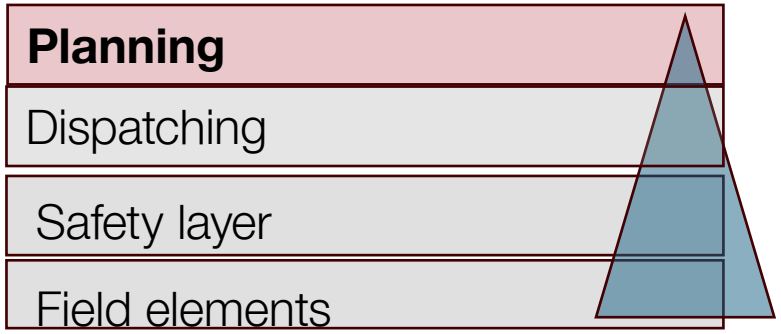
Source: stellwerke.info

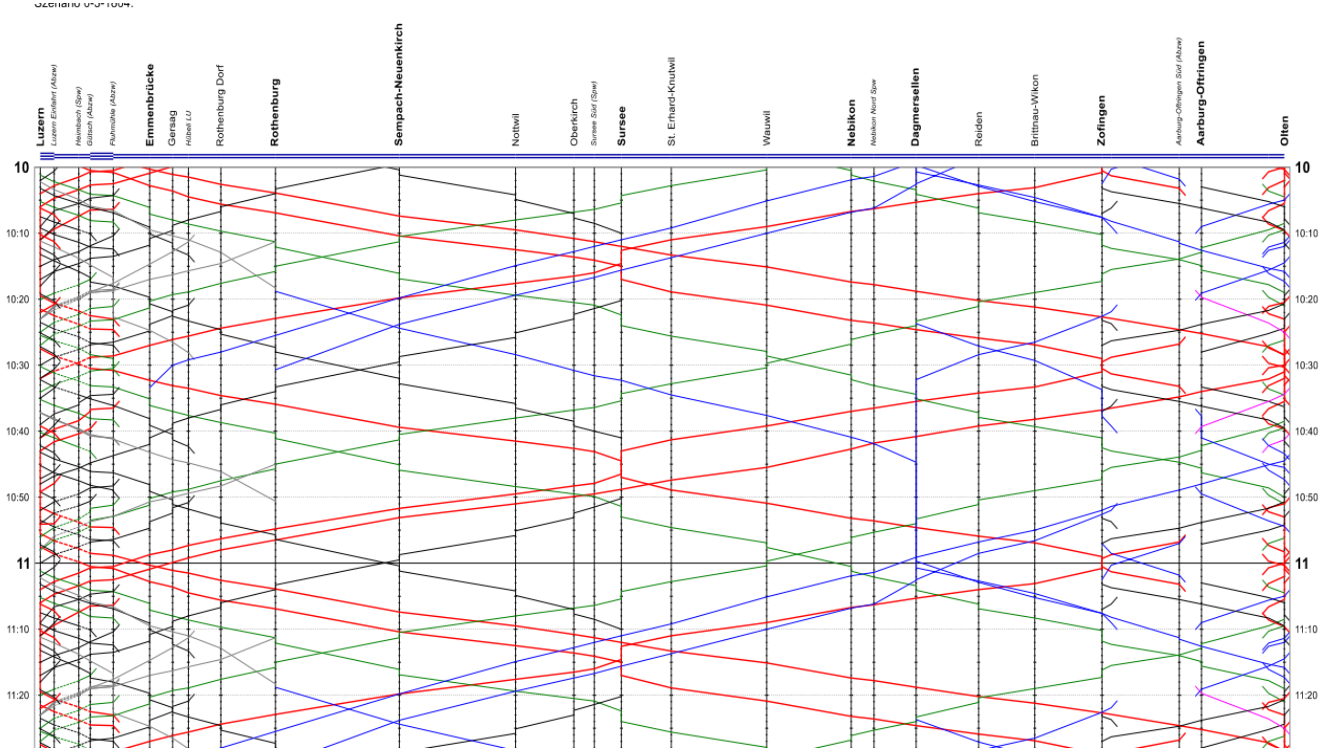
Train control centre (TCC) Renens:

- Train control centre for the western region.
- Manages majority of rail traffic in western Switzerland.
- Ensures efficient monitoring and control of the network.

Planning Layer.

Will be discussed in lectures 9 and 10 .





Wrap-up: short summary on all essential system layers and their contribution to safety and capacity.

			Safety relevance	Capacity relevance
Planning	Annual and daily timetabling	Centralized planning offices	Very low	High
Dispatching	Regulating traffic and fixing disturbances	4 operations centres	low	High
Safety layer / Interlocking	Ensuring safe movements on the tracks	100s of interlocking	Very high	Low
Field Elements	Safely executing movements on the tracks	1000s of signals, switches, trains	Very high	Low

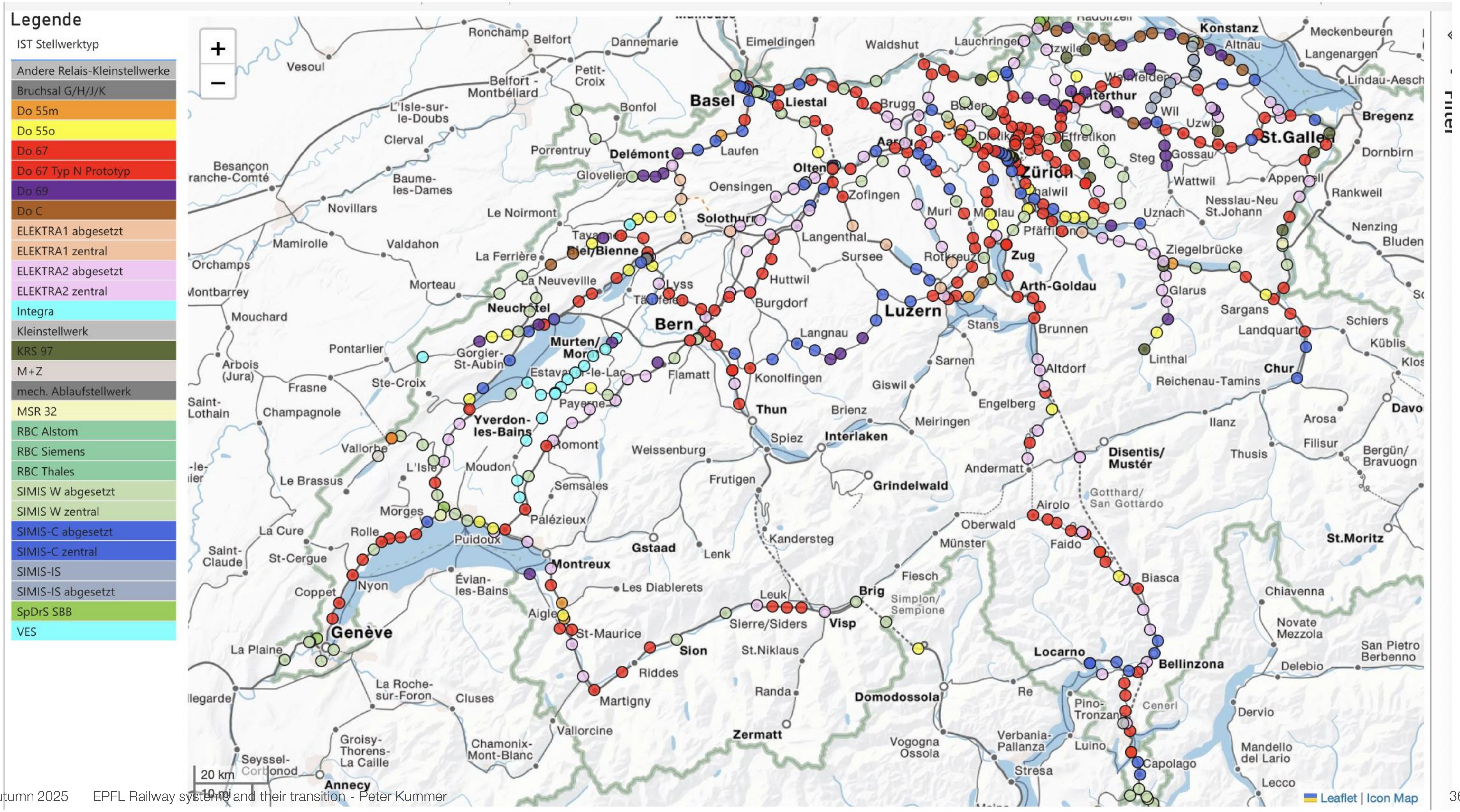
From the bottom to the top we have

- Increasing centralization
- Increasing responsibility for capacity and punctuality
- Decreasing responsibility for safety

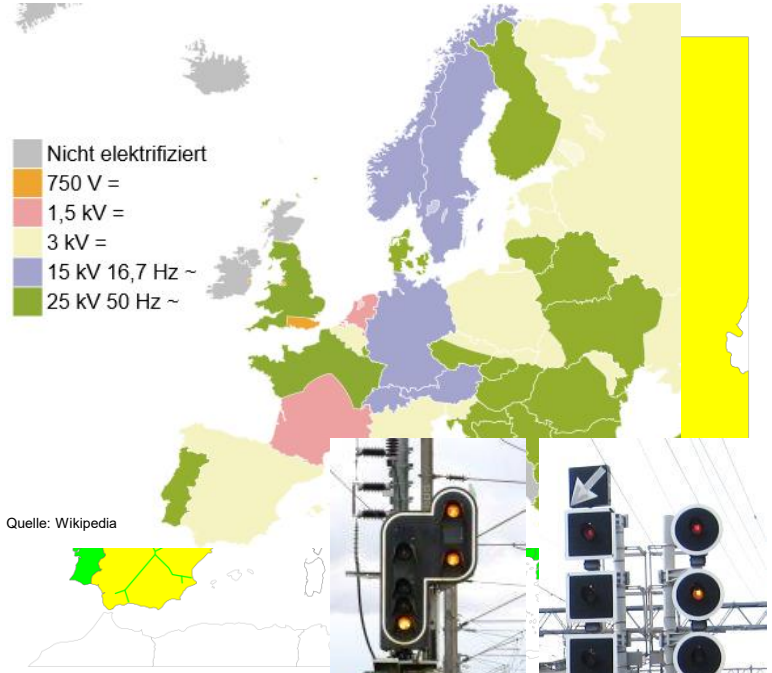
Layered architecture

- ensures a safety «gatekeeper» for the physical world
- allows freedom for optimization in upper layers

3. National railway development and its challenge for Europe.


Legende
IST Stellwerktyp
Andere Relais-Kleinstellwerke
Bruchsal G/H/J/K
Do 55m
Do 55o
Do 67
Do 67 Typ N Prototyp
Do 69
Do C
ELEKTRA1 abgesetzt
ELEKTRA1 zentral
ELEKTRA2 abgesetzt
ELEKTRA2 zentral
Integra
Kleinstellwerk
KRS 97
M+Z
mech. Ablaufstellwerk
MSR 32
RBC Alstom
RBC Siemens
RBC Thales
SIMIS W abgesetzt
SIMIS W zentral
SIMIS-C abgesetzt
SIMIS-C zentral
SIMIS-IS
SIMIS-IS abgesetzt
SpDrS SBB
VES
Basel
Liestal
Delémont
Olten
Solothurn
Biel/Bienne
Neuchâtel
Bern
Luzern
Zürich
Winterthur
St.Gallen
Konstanz
Zug
Arth-Goldau
Chur
Thun
Interlaken
Brig
Visp
Sion
Montreux
Lausanne
Genève
Yverdon-les-Bains
Bellinzona
Locarno
Domodossola
Zermatt
Leaflet | Icon Map
20 km

Barriers to interoperability.



Quelle: Wikipedia

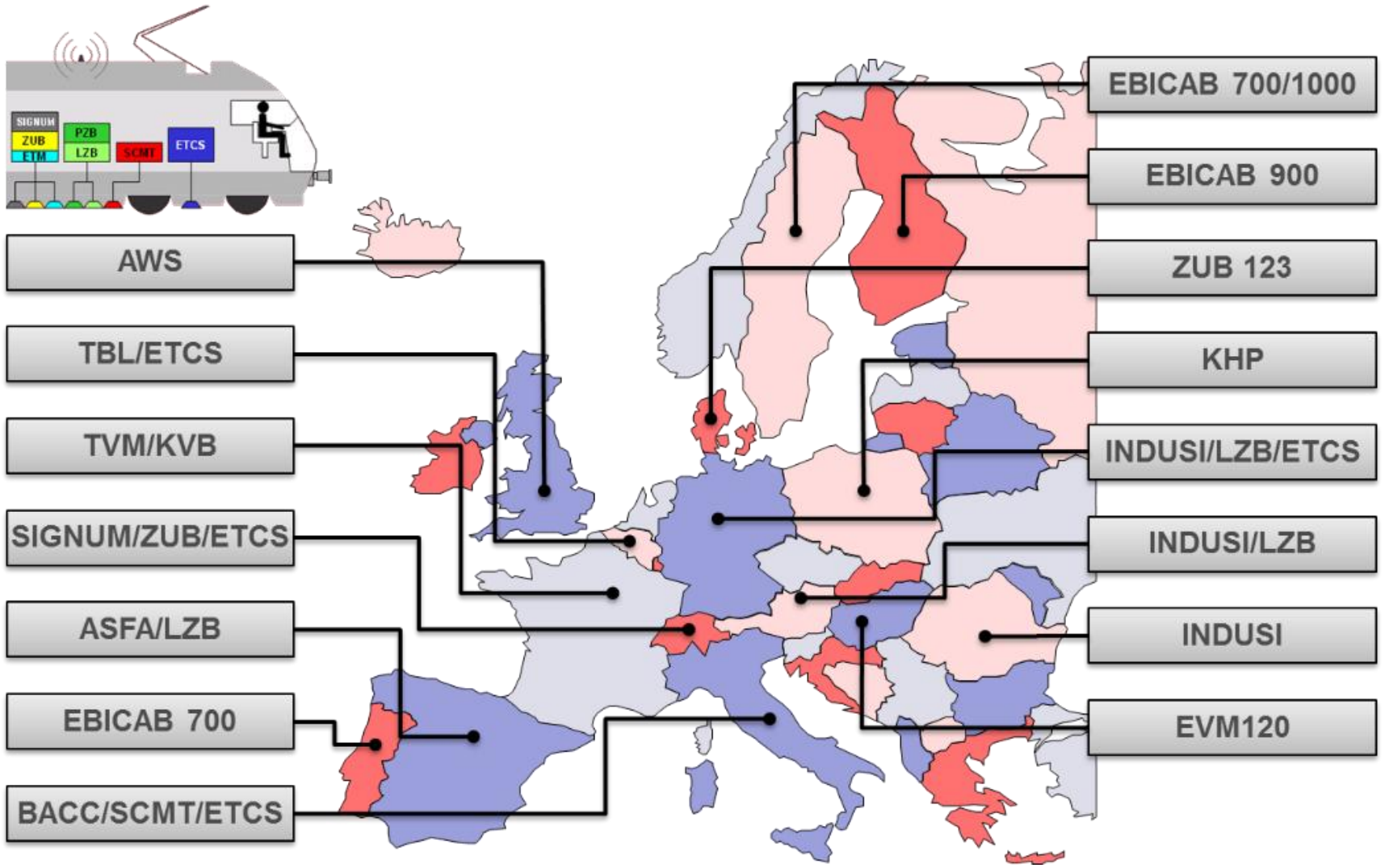
Source: Wikipedia

Barriers to interoperability in rail transport have often arisen for **historical reasons**.

Individual railway companies adopted different solutions in various areas of the railway system, such as:

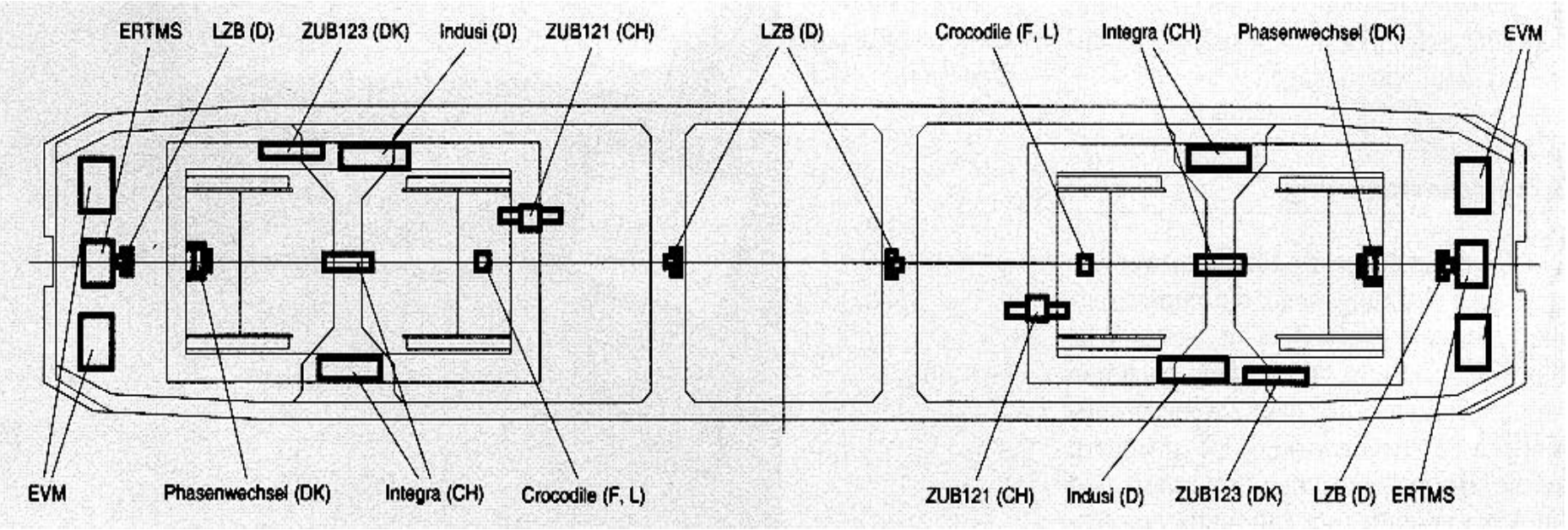
- track gauge
- power supply system
- loading gauge / structure gauge
- **operating rules**
- **signalling system**
- **train protection (train control)**

Train control systems in Europe.

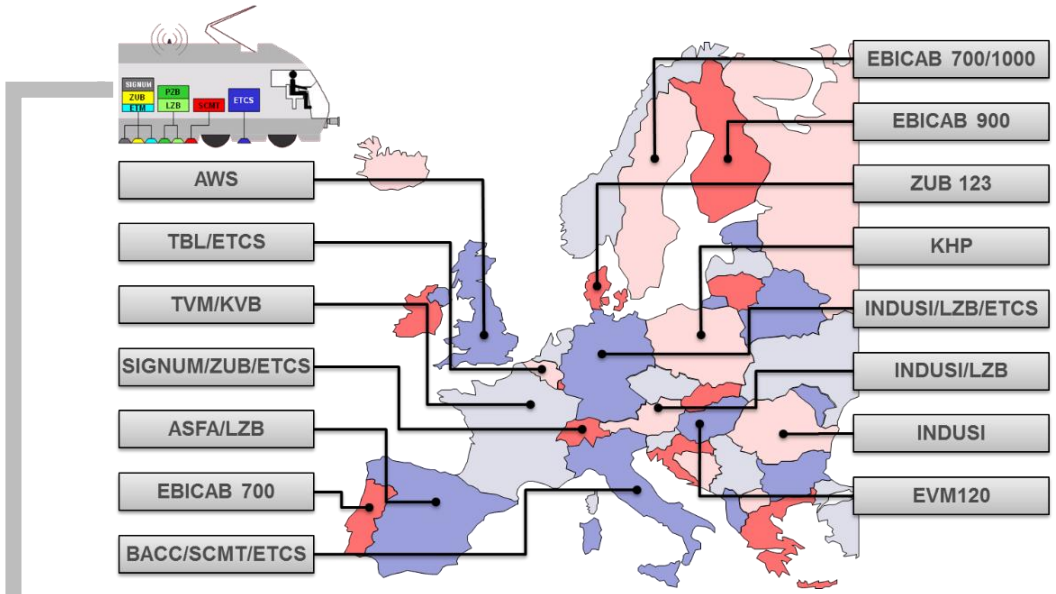


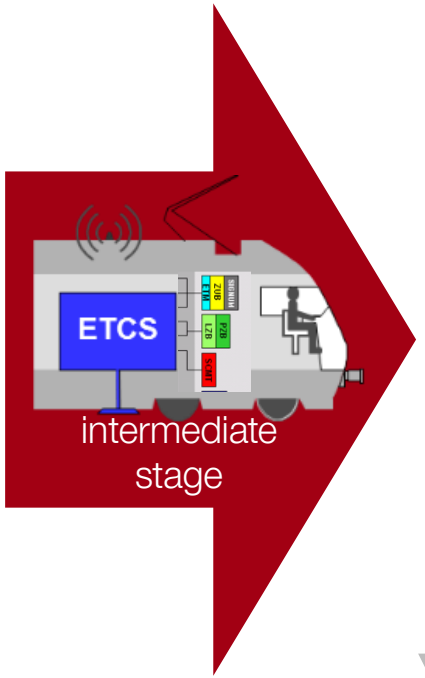
Consequences for a traction unit.

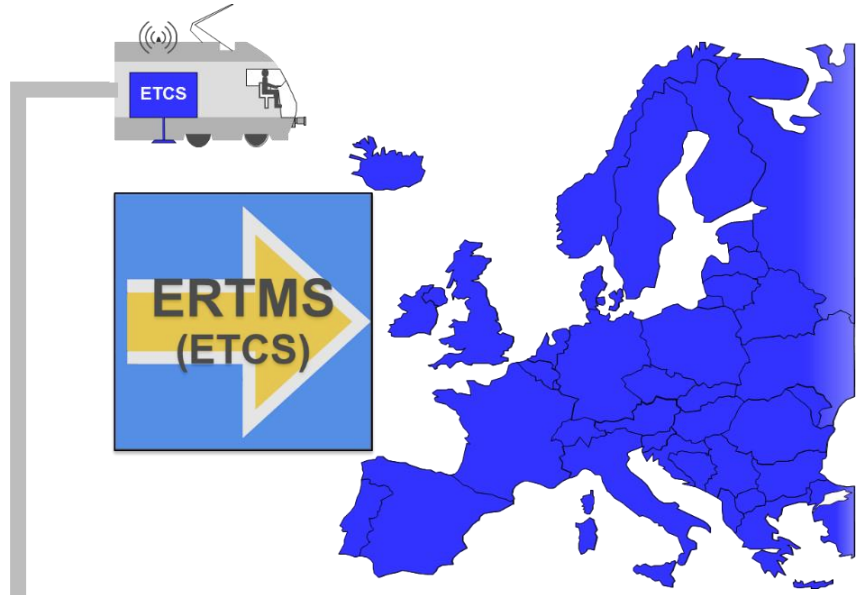
If a traction unit is to be used throughout Europe, **this requires relatively extensive equipment with all existing train protection systems.**
DBs BR 185 is used, for example, in Germany, Denmark, Norway, Sweden, Luxembourg, France, Switzerland, Austria and Hungary.



Interoperability in practice.
Train protection – ETCS as a marathon.







France:
Crocodile Contact brush

Source: Wikipedia Zugbeeinflussung

Italy:
SCMT-Antenna

modellismotropea.blogspot.com

Germany:
LZB-Antenna

Wiki - Linienförmige Zugbeeinflussung

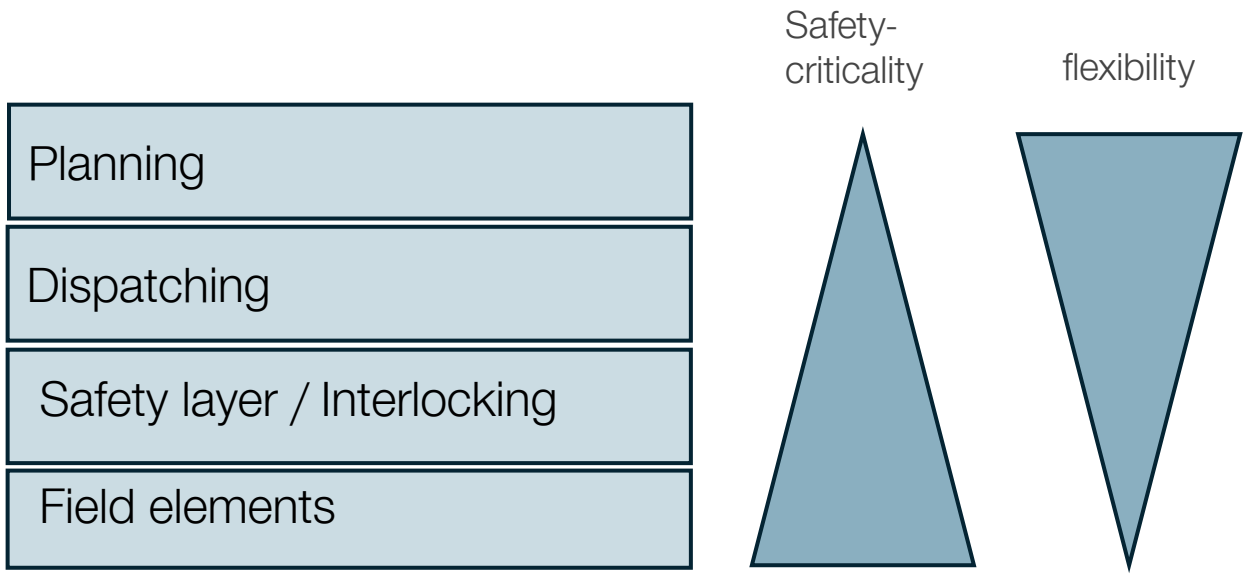
Europe:
ETCS antennas and Eurobalises

de-academic.com

ETCS European Train Control System
ERTMS European Rail Traffic Management System

4. Improving efficiency through digitalization.

Digital Transformation: the Planning and Dispatching layers are not safety-critical and based on modern IT technology, they are the preferred place to implement innovations.



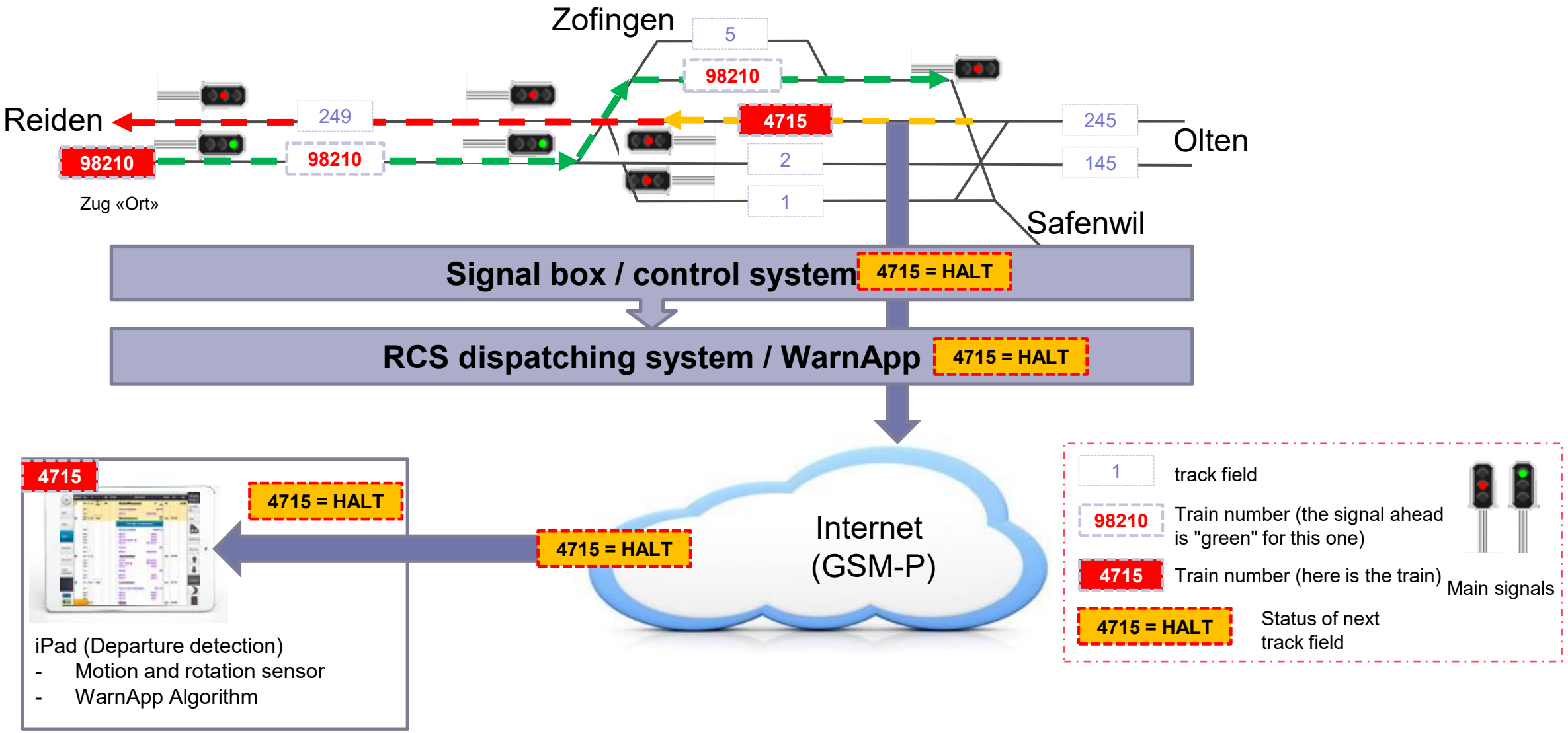
Examples of innovative optimization and assistance functions implemented in the planning and/or dispatching layer

- WarnApp Zug
- Driver assistance
- Real-Time Optimization
- Open Data

WarnApp Train: Initial situation.

After the accident in Granges-Marnand on July 29, 2013, when a train left despite the stop signal, possibilities were quickly sought to increase safety.

WarnApp Zug: Solution – Principle of operation.



WarnApp Zug: Solution – warning display.

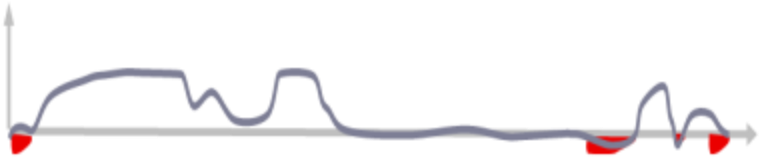
When the WarnApp warns, it is displayed visually, and the warning tone sounds at the same time.
In order to maintain acceptance among locomotive personnel, there are ways to justify a warning

1. Acknowledgement
2. Manoeuvre
3. False Warning

Driver assistance: An intelligent dispatching layer provides speed recommendations to the train drivers.

Driver assistance: Example for ADL (speed recommendation).

without ADL:

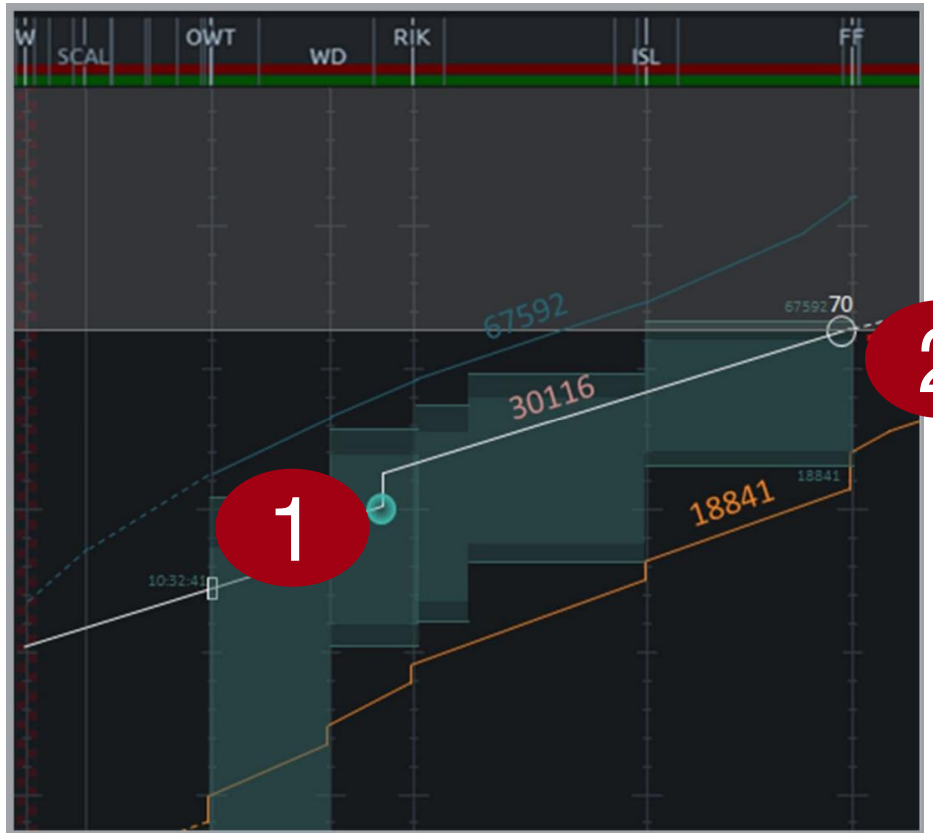


Energy consumption: 350 kWh,
Travel time 651 s

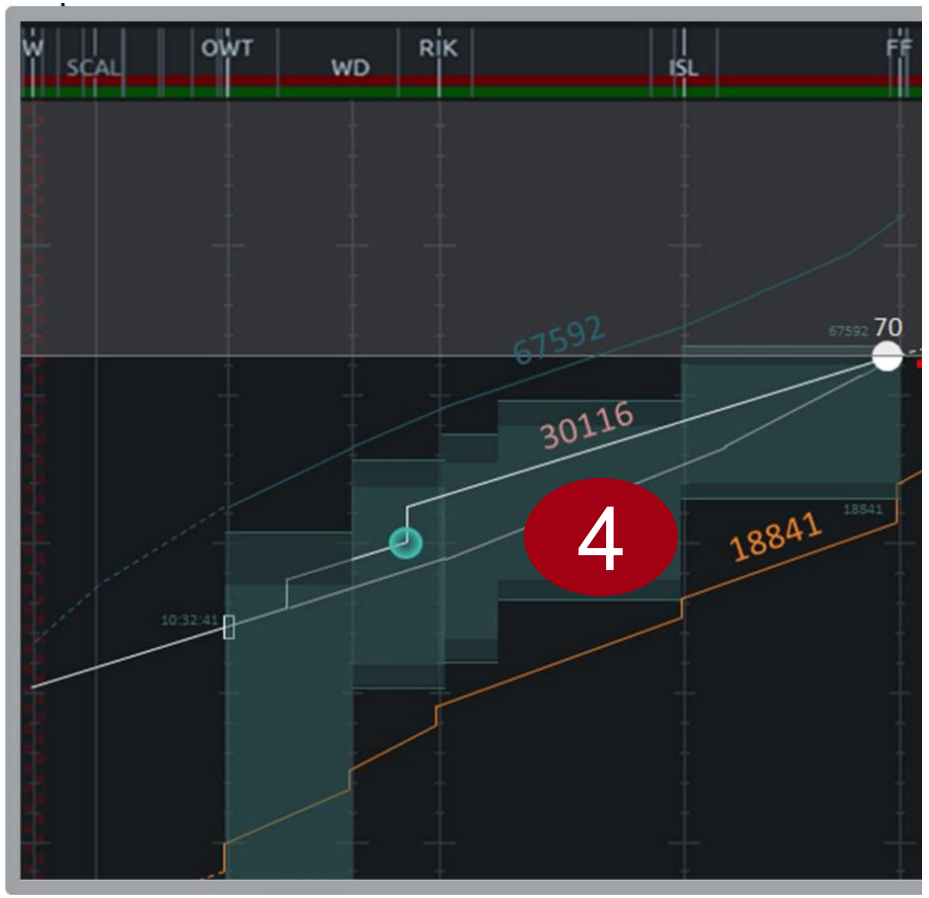
With ADL:

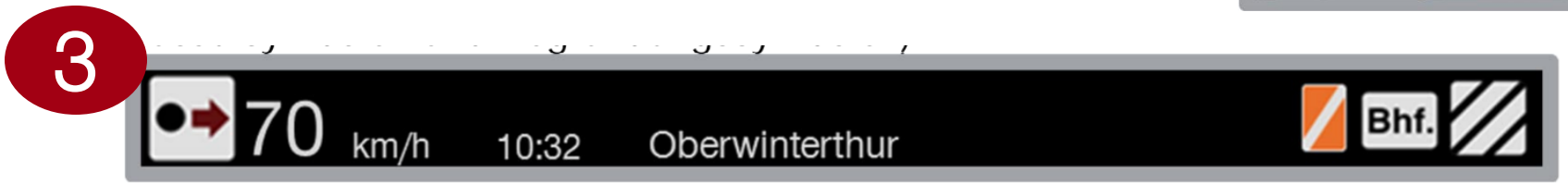
Energy consumption: 204 kWh, -40%!
Travel time 626 s

Driver assistance: Example for ADL (speed recommendation).

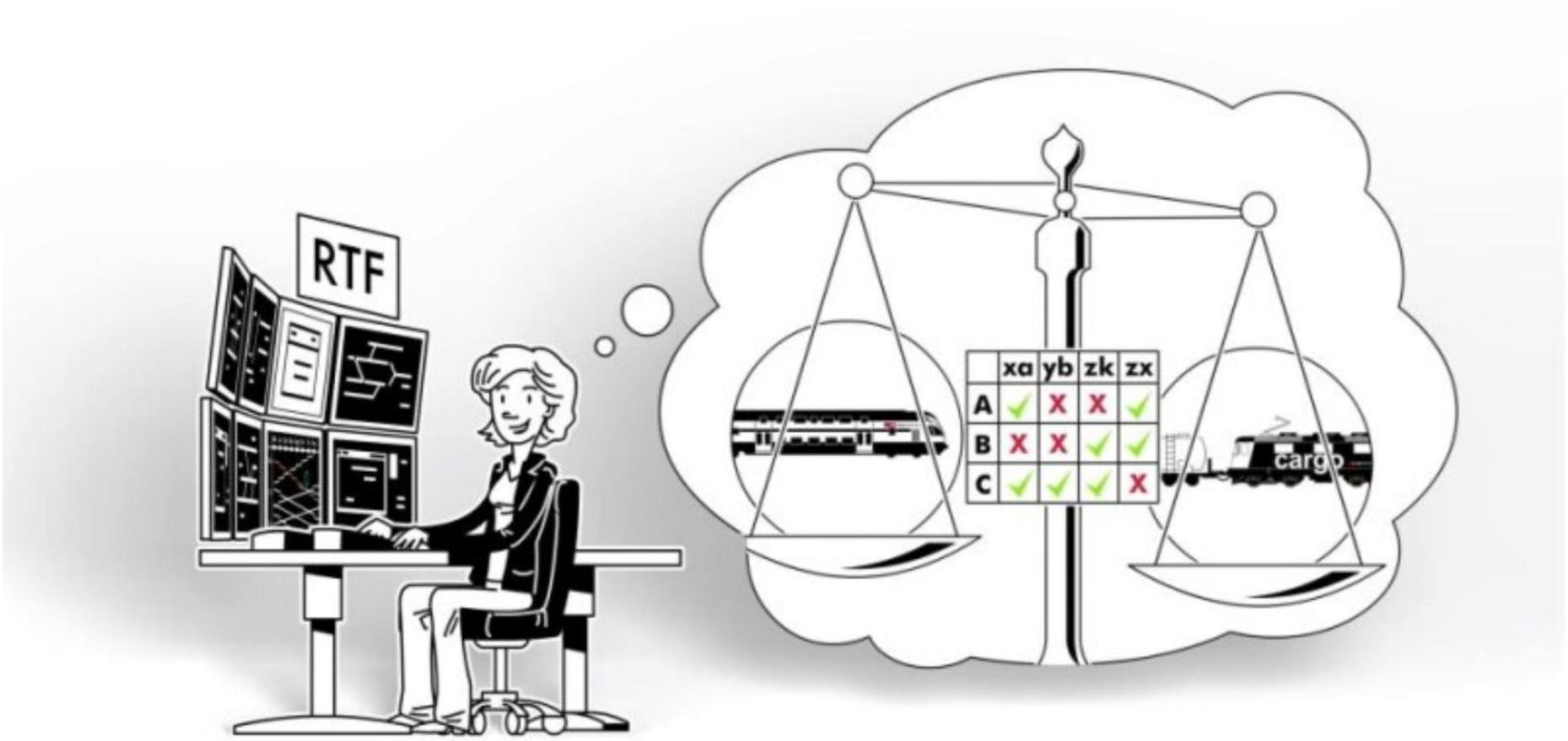


1. Detected conflict
2. Calculated new speed
3. Message to train diver
4. Corrected path with new speed





Adaptative regulation (ADL).



RTO “Real-Time Optimisation” automatically resolves conflicts recognised in the current production plan.

Conflict resolution optimised by RTO takes place in two ways:

- Sequence changes and / or
- Route changes

Thanks to **the control access to the Iltis control** technology with the DispoOp module, the optimisations are implemented automatically.

So-called **"simple" areas are currently being algorithmically optimised**. For more complex areas, the prerequisites for authorisation and the availability of E2E topology data must first be created.

Vision: The potential for optimisation applications is increased by including all capacity-using objects (train and shunting movements, stabling, track closures, etc.) and gradually expanding the areas.

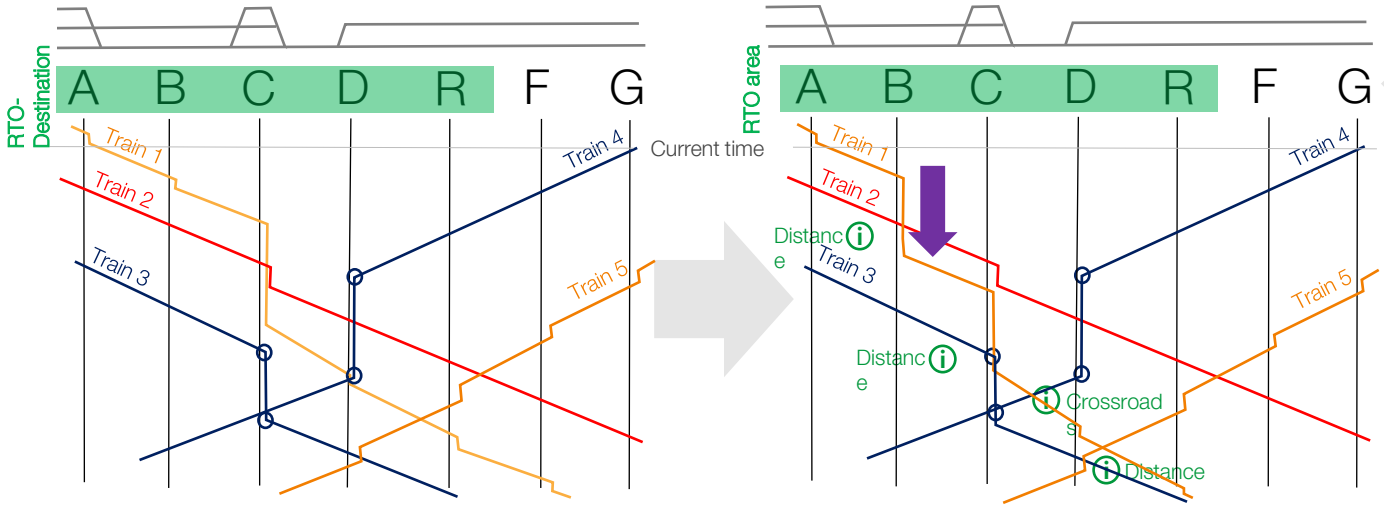
What are the **effects** of RTO?

- supports the **robustness / stability**
- **increases capacity** through **efficient** and **flexible** processes
- minimises risks = increases **safety**

How does RTO work?

RTO is technically capable of resolving conflicts recognised by RCS within a defined area in two ways:

TARGET timetable



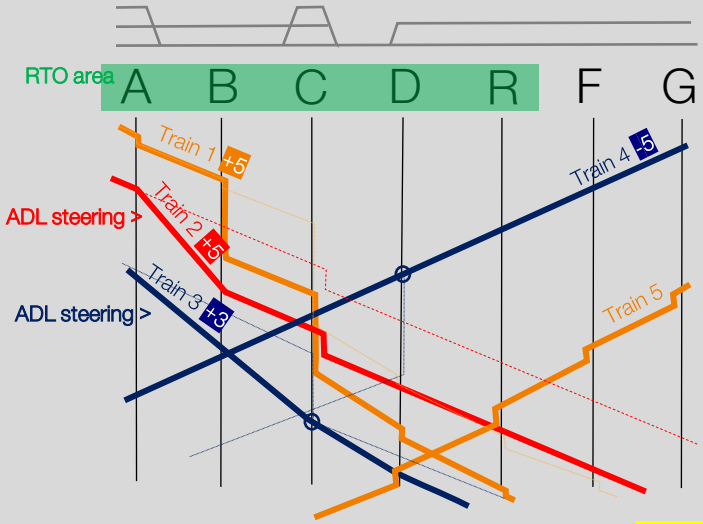
Traindriver1 reports problems with the vehicle > Reset in B necessary

1) Dispatcher pulls down departure forecast 5 minutes after

2) TMS recognises and visualises emerging conflicts

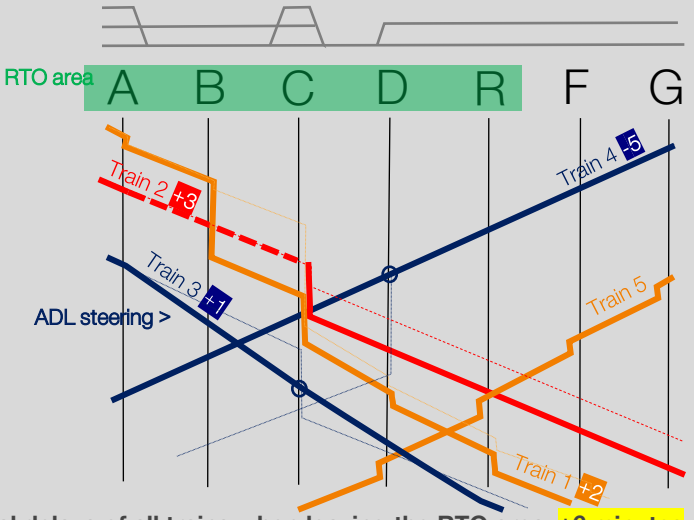
3) RTO calculates possible solution variants, calculates the resulting delays and selects the variant with the lowest overall impact

Conflict resolution by means of order dispositions



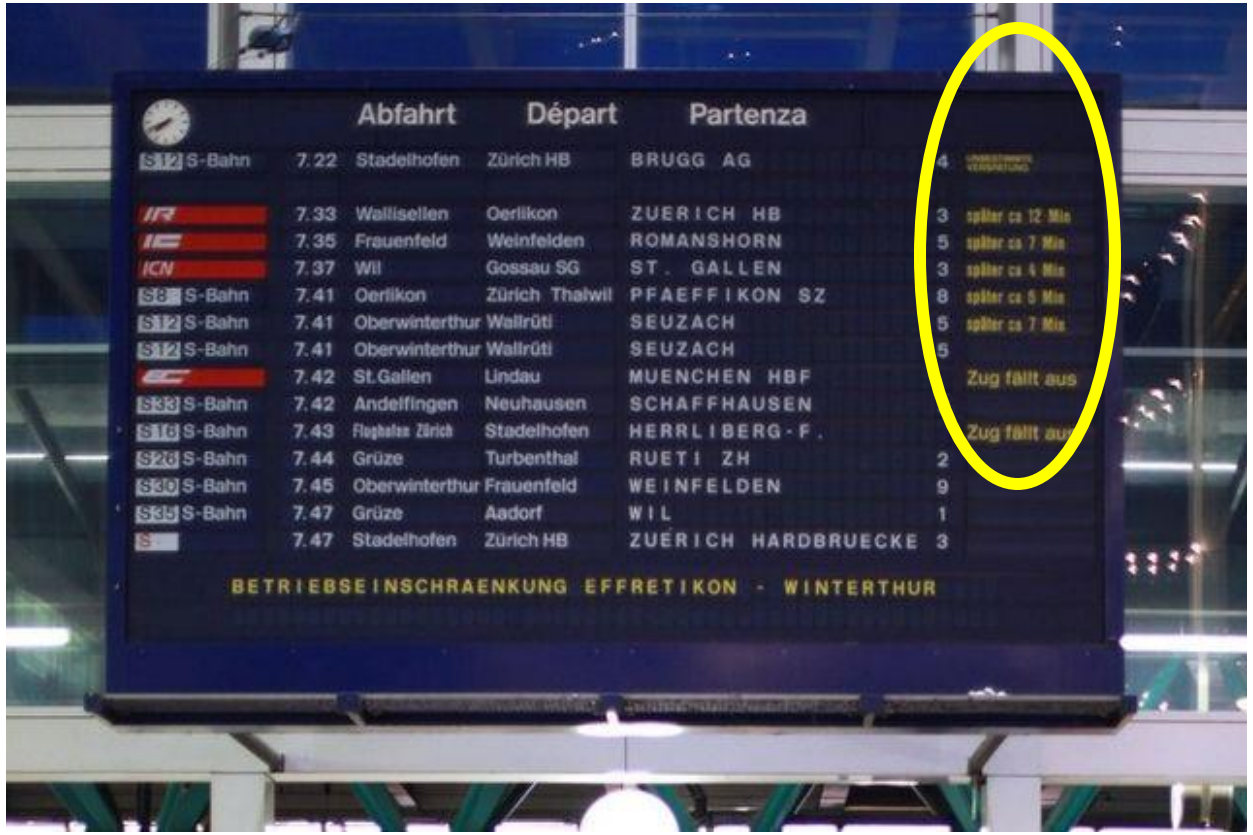
Total delays of all trains when leaving the RTO area: +13 minutes

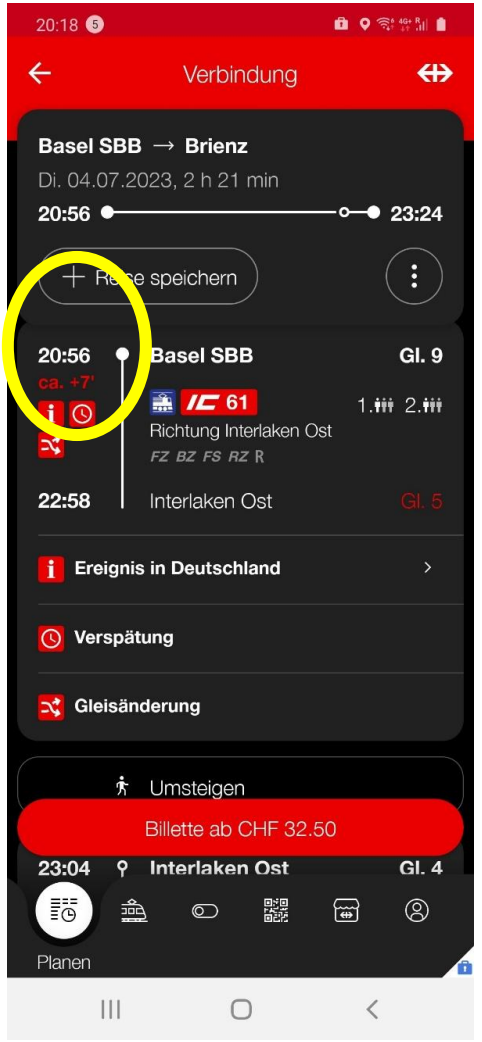
Conflict resolution by means of sequence and route planning



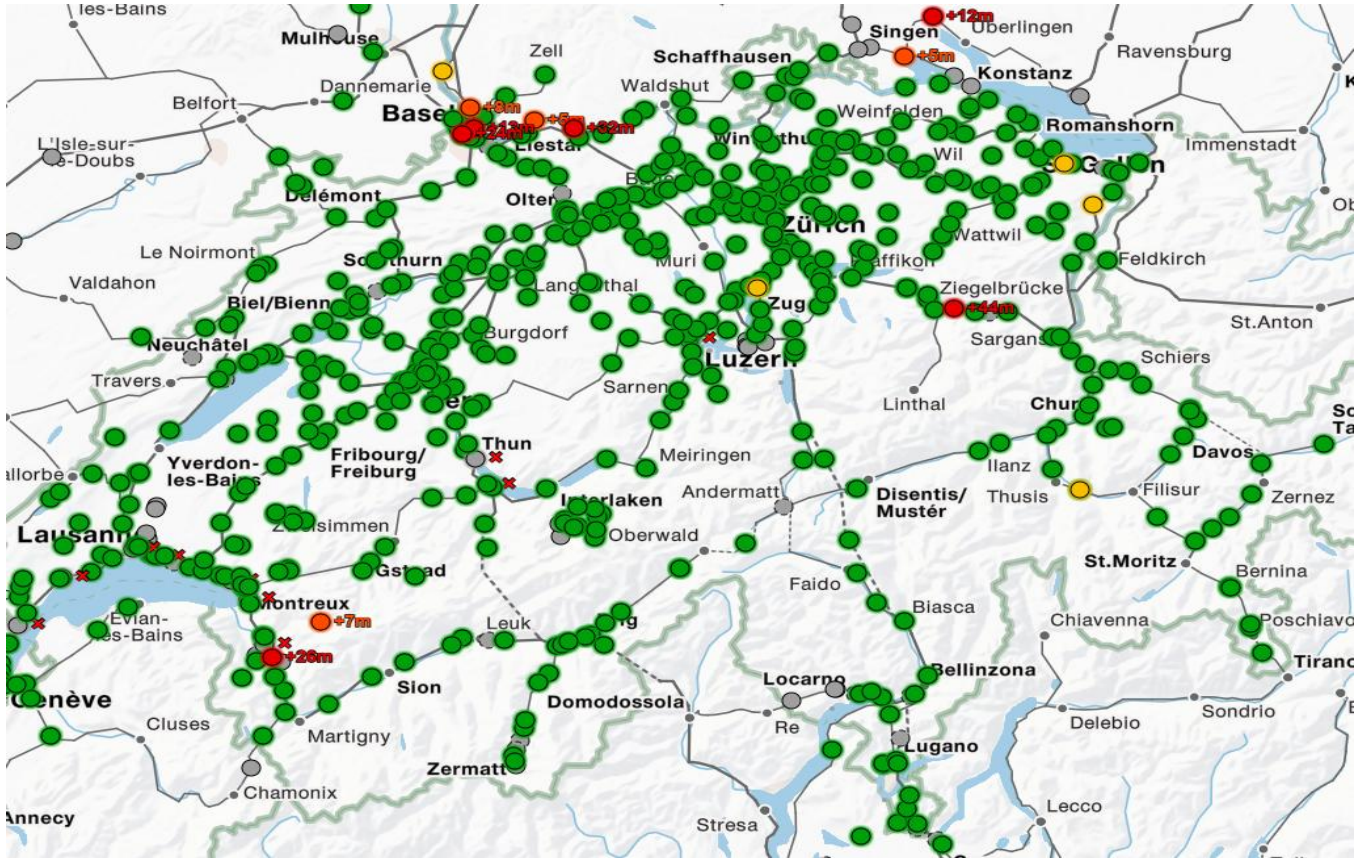
Total delays of all trains when leaving the RTO area: +6 minutes

Other uses of the production plan: How a centralized overview of railway traffic and train delay forecast enable coherent customer information.





Other uses of the production plan: Train data is shared via open data interfaces and enables third parties to integrate into the eco-system.



[LINK]

5. Outlook.

ETCS Level 2: Cab Signalling.

Major Challenges in Switzerland.

Upgrade

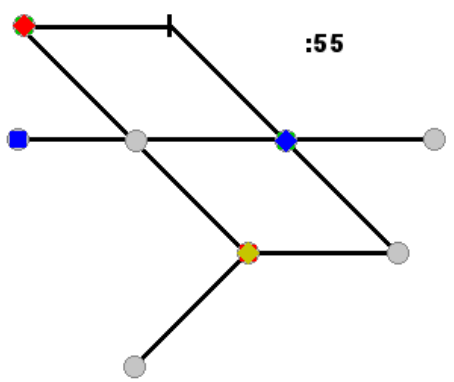
Existing Infrastructure

Construction during
Train Operation

Mixed Traffic

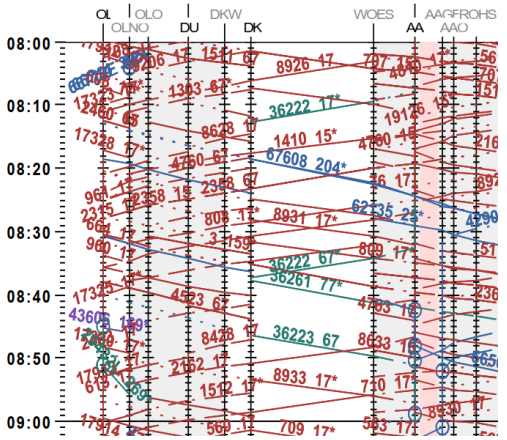
Suburban & Regional Trains
Fast Passenger Trains
Express Freight Trains
Standard Freight Trains

Fixed Interval Timetable



Fixed Operational Concept
Guaranteed Connections

High Density of Train Traffic



Short Train Headway

ETCS Level 2 @ SBB.

With most advanced opportunities.

international traffic on **ETCS Standard**	→ **Interoperability of Train Control** → national Train Control obsolete
very short Signal Blocks possible	→ minimal Occupation of Signal Blocks → **very short Train Headways**
Lineside Signalling obsolete	→ more **flexible Signal Block Allocation** along twisting routes → visually independent from **Curves, Narrow Tunnels**
Train-specific Braking Distances	→ **Fixed Approach Signal Distances** obsolete → **Harmonisation of Speeds** by Increase of Speed for freight trains
Instant Speed Increase from Signals	→ **instant Acceleration** after increase of signalled speed → **reducing Train Delays** in Train Routing Conflicts
Foresight of Driver more than signal block	→ **predictive Driving & Speed Regulation** → more continuous Braking, less intermittent Braking
Base for Automation & Digitalisation	→ shorter response times, **more precise Driving**, reduced Driving Variation → digital **Automation of Planning & Operating Procedures**
International **Product Standardisation**	→ **Procurement Advantages** by Economies of Scale → Harmonisation of **Spare Part Management**

Source: I-NAT-NET-KNP
S.Baumgartner, 05.2025

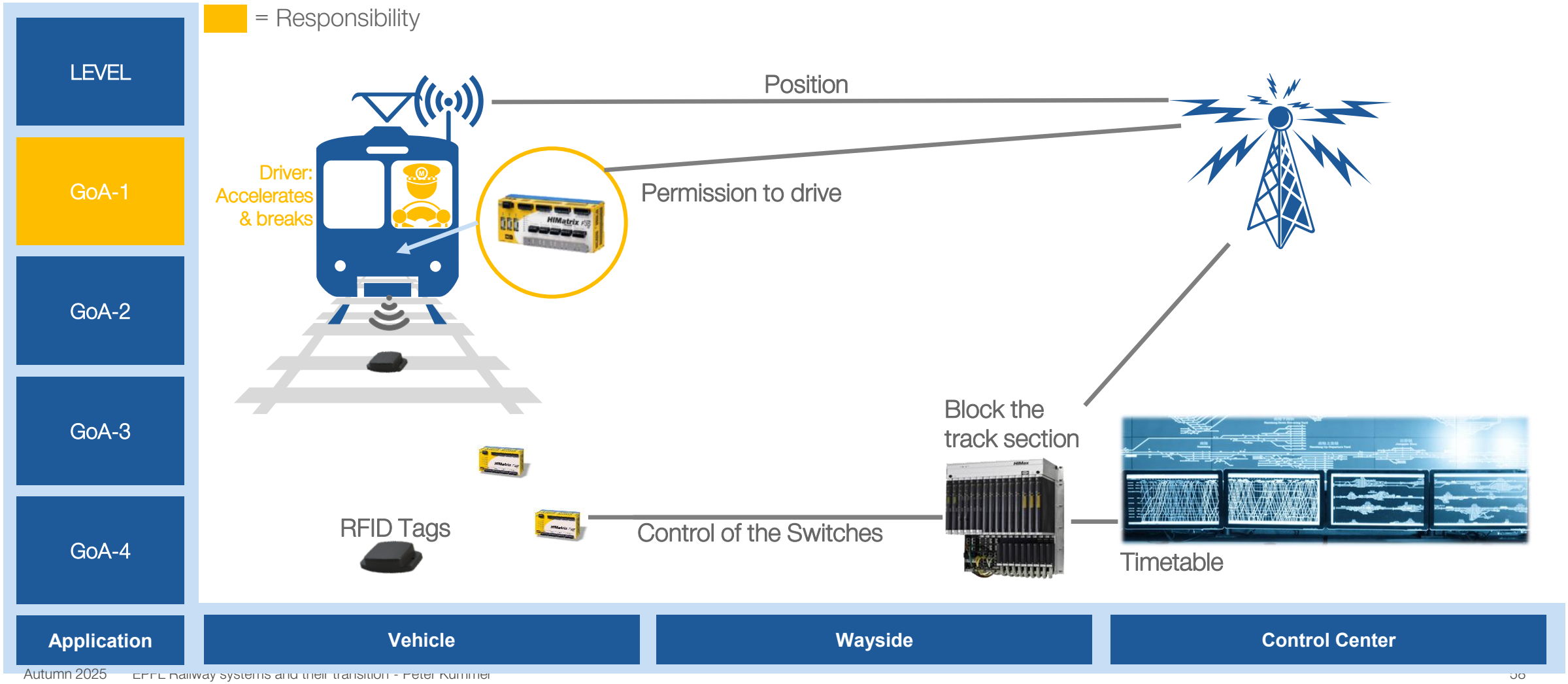
Automation – Automatic Train Operation (ATO).

According to IEC/EN 62290-1, the following levels of automation are distinguished:

- **GoA 1** (Grade of Automation)
  Manual Driving with Cab Signalling and Train Control
- **GoA 2**
  Automatic driving with the constant presence of a train driver to intervene in the event of a malfunction and special operating procedures
- **GoA 3**
  Automatic driving with the presence of personnel on the train who can intervene in the event of a malfunction
- **GoA 4**
  Fully automated system with no personnel on the vehicles

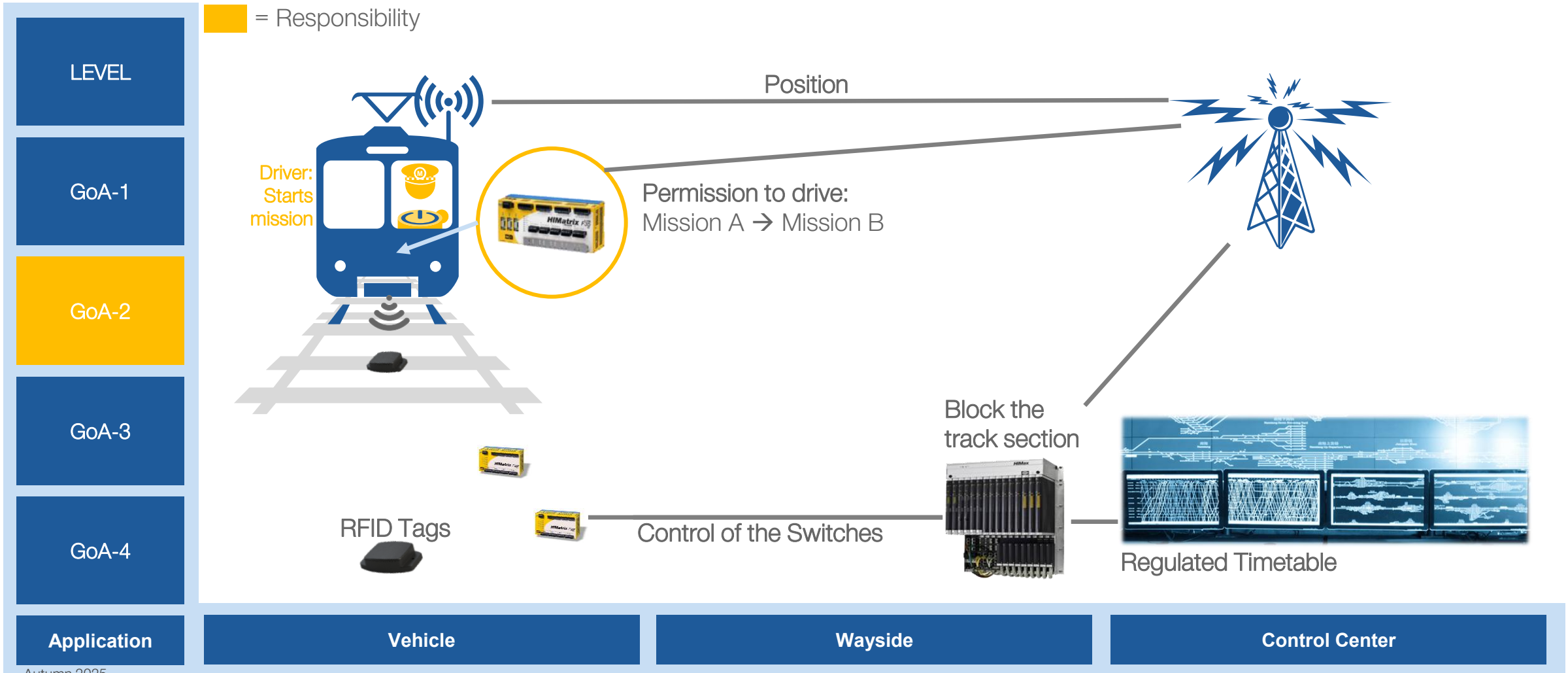
Example Stadler CBTC.

GRADES OF AUTOMATION



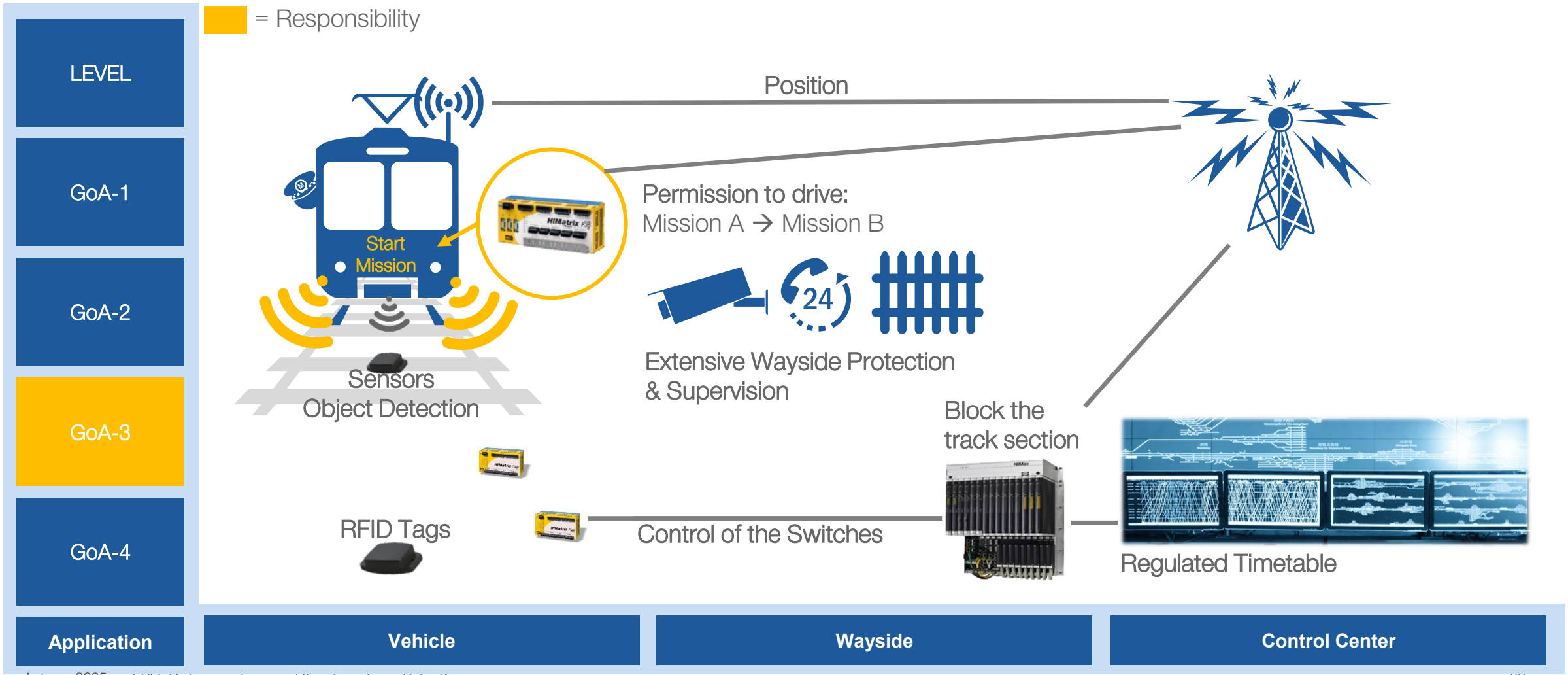
Example Stadler CBTC.

GRADES OF AUTOMATION



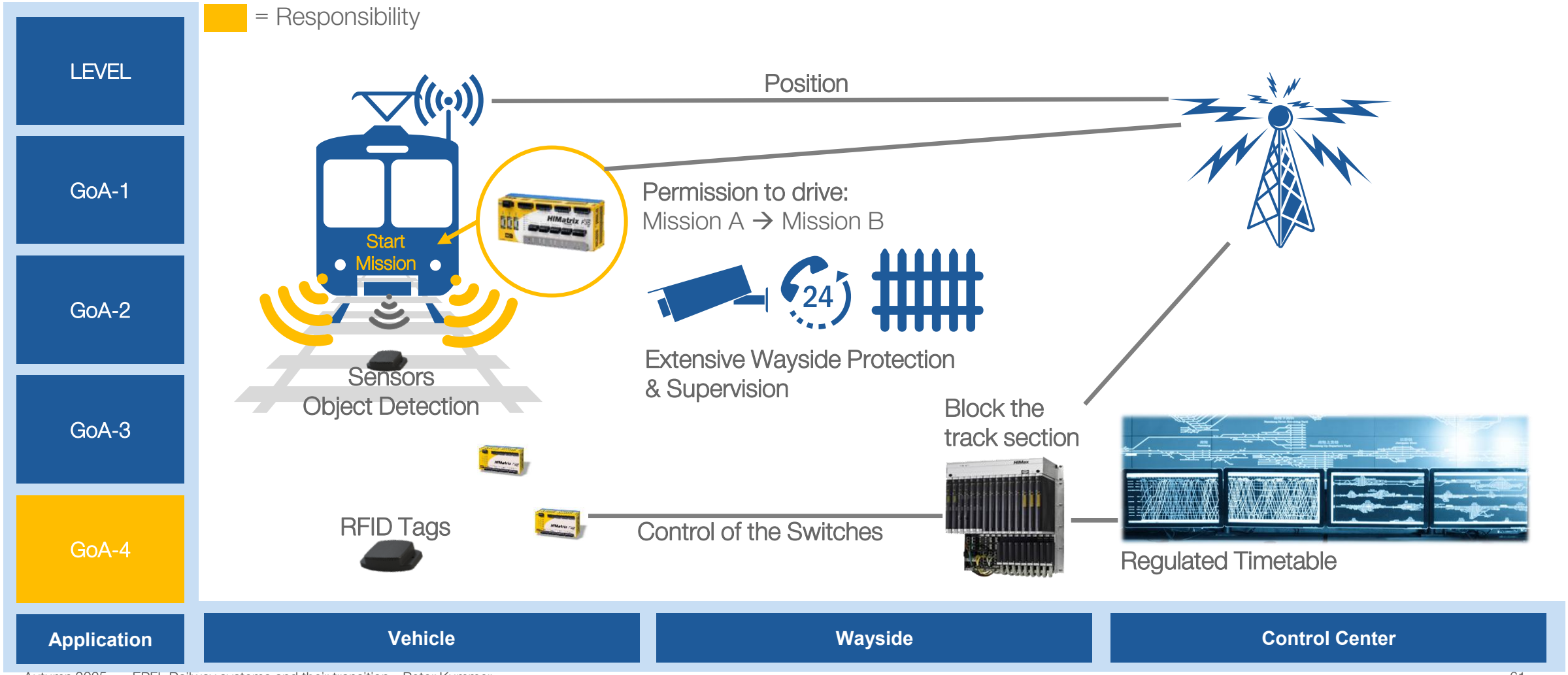
Example Stadler CBTC.

GRADES OF AUTOMATION



Example Stadler CBTC.

GRADES OF AUTOMATION

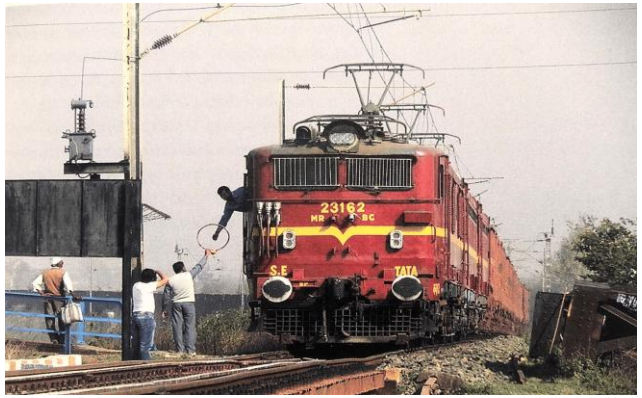


Increased infrastructure utilisation – versus safety.

operating at sight distance

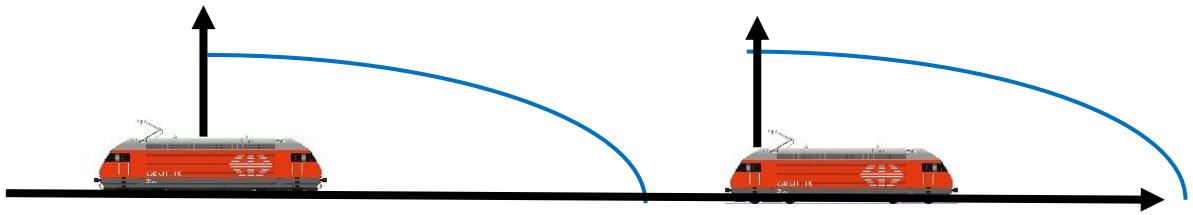
Source: Berner Zeitung

operate with absolute spacial separation

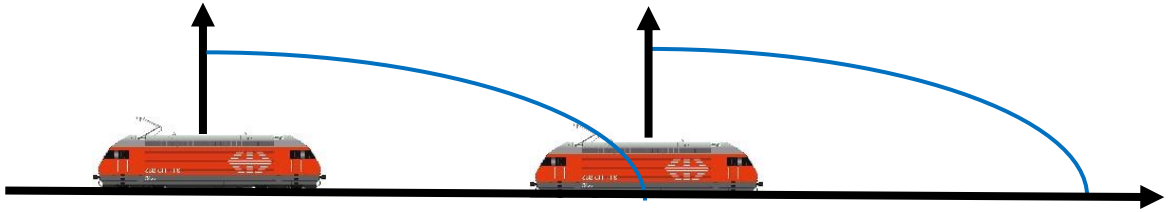


Source: Praxishandbuch Bahnsicherung

operate with absolute spacial separation



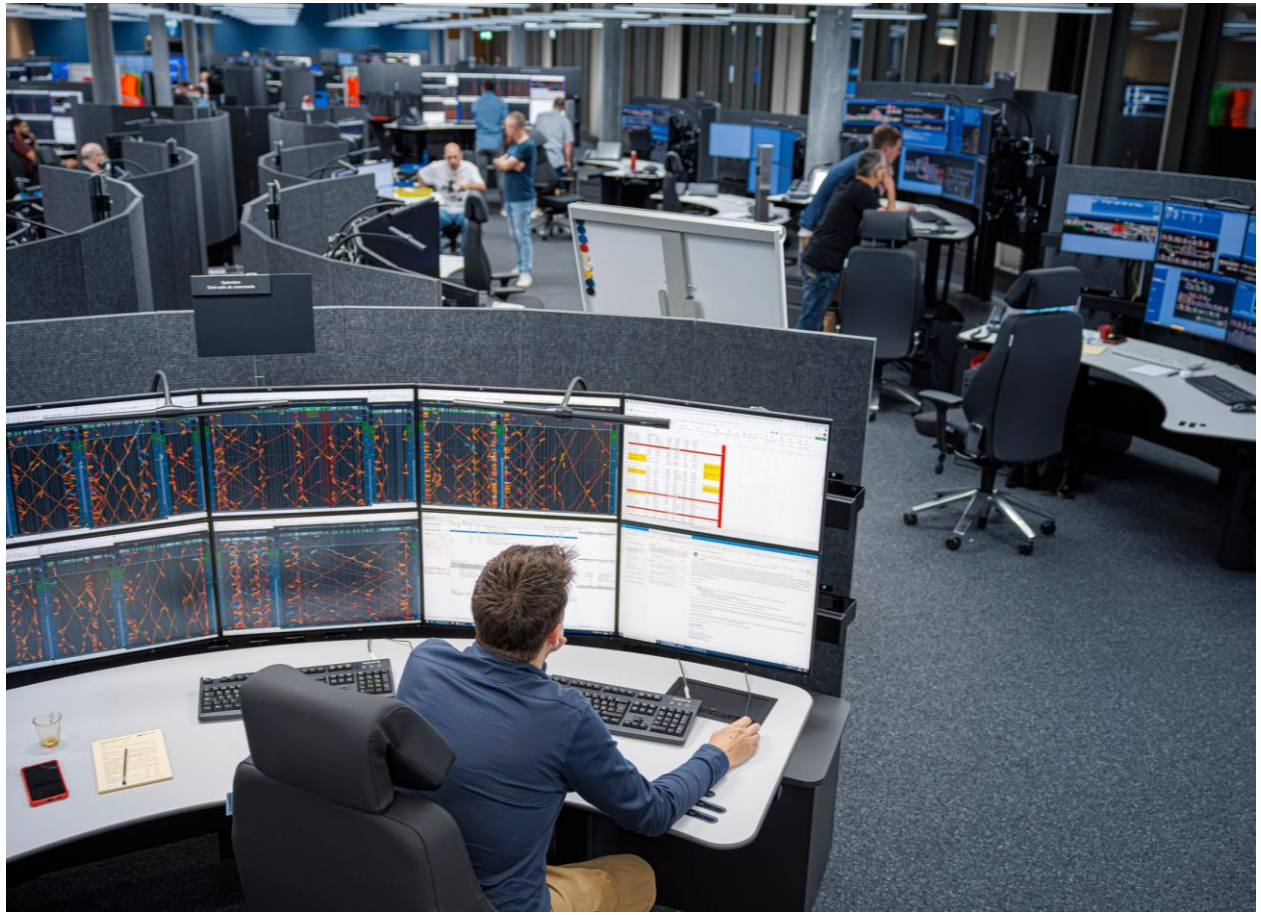
operate with relative spacial separation



Conclusion.

What to take away?

Take-away messages.

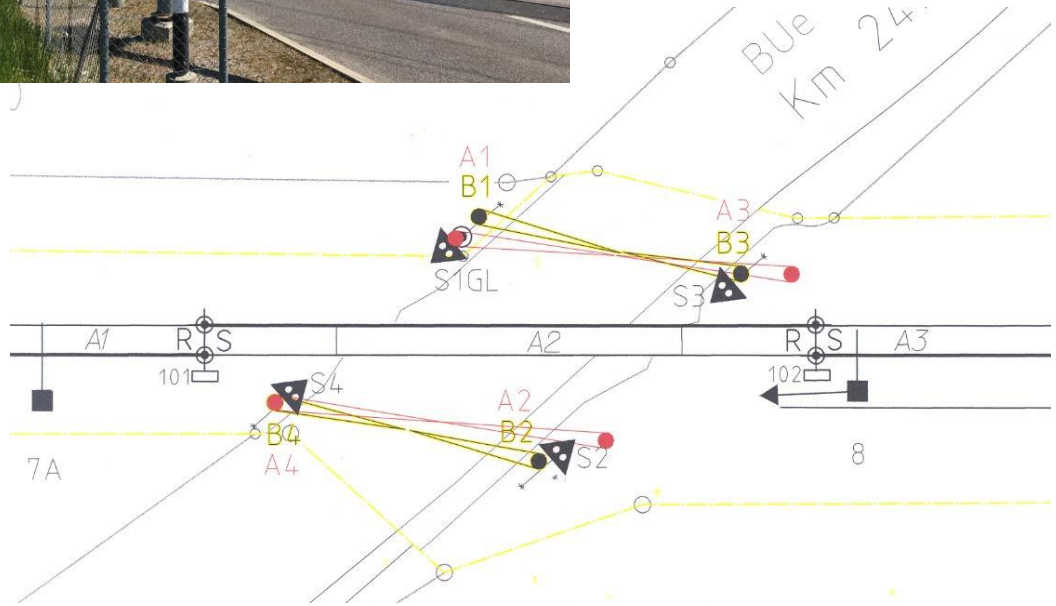


1. Rail is a highly efficient mode of mass transport.
2. It requires intensive technical measures to ensure safety.
3. Control is centralised by the infrastructure and has many dependencies.
4. Through the digitalisation of business processes, there is significant optimisation potential, which is currently being implemented.

Case Study Traffic Management Systems.

Case Study for next week.

Level crossing case investigation.



Description
- 1 train every 15 min
- Track
- Main road (incl. pedestrian)

Questions
- What hazards exist and how can they arise?
- How many accidents occur?
  - Are accidents caused by technical failures or human error?
  - What is the probability of a technical failure versus human error?
- What are the implications for this level crossing system?
- What does this imply for about 4,000 level crossings in Switzerland?
- What are the impacts on rail transport?
- What design principles should be applied to level crossings to reduce technical failures (SIL)?