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Railway operations research and the development of digital railway traffic systems

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Railway traffic systems

**Strategic**
- Transport Demand
- Network Design
- Rules and Procedures

**Tactical**
- Timetable Design
- Disruption Management

**Operational**
- Traffic Management
- Signalling
- Train Operation
- Train Positioning

- Disruptions
- Driving Error
- Information
- Deviations
- Disturbances
- Structural Delays
- Capacity Saturation
Outline

- Objectives and challenges
- Automatic Train Operation
- Digital railway traffic systems
- Digital railway traffic system evolution
- Conclusions
**Objectives**
- Short travel times
- Punctuality
- Capacity
- Reliability
- Flexibility
- Sustainability
- Safety
- Cost-effectiveness

**Challenges**
- High frequencies
- Short headways
- Fast overtaking
- Running at seconds
- Green waves
- Stable operation
- Minimal disruptions
- Energy efficiency

**Innovations**
- Digital railway traffic systems
Digital Railway Traffic System Components

Wireless Communication and Signalling

Automatic Train Operation

Intelligent Traffic Management

Automated Timetabling
Automatic Train Operation (ATO)

Goal
• Automation of train driving tasks towards supervisory or autonomous train control, enabling improved
  ❑ Punctuality
  ❑ Capacity
  ❑ Energy efficiency
  ❑ Flexibility
  ❑ Cost effectiveness

Main functions
• Automated accurate driving
• Accurate stopping
• Automated turning
• Automated shunting
ATO in metro systems for over 50 years

London Victoria Line (1969)
- Grade of Automation 2 (GoA 2)
- Automated driving from stop to stop
- Driver in cab responsible for door closing, obstacle detection and emergency situations

London Docklands Light Railway (1987)
- GoA 3
- No driver

VAL Lille (since 1983)
- GoA 4
- Also dwelling automated
- No supervision on board
## Grade of Automation (GoA)

<table>
<thead>
<tr>
<th>Grade of Automation</th>
<th>Train operation</th>
<th>Starting</th>
<th>Driving and stopping</th>
<th>Door closure</th>
<th>Operation during disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GoA 1</strong></td>
<td>Manual (ATP with driver)</td>
<td>Driver</td>
<td>Driver</td>
<td>Driver</td>
<td>Driver</td>
</tr>
<tr>
<td><strong>GoA 2</strong></td>
<td>Semi-automatic (STO)</td>
<td>Driver/A</td>
<td>Automatic</td>
<td>Driver</td>
<td>Driver</td>
</tr>
<tr>
<td><strong>GoA 3</strong></td>
<td>Driverless (DTO)</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Attendant/A</td>
<td>Attendant</td>
</tr>
<tr>
<td><strong>GoA 4</strong></td>
<td>Unattended (UTO)</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
</tbody>
</table>

Note: without ATP the Grade of Automation is GoA 0 (on-sight train operation like tram)
ATO on mainline railways?
### Metro versus mainline railways

<table>
<thead>
<tr>
<th>Metro</th>
<th>Mainline railways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous traffic</td>
<td>Heterogeneous traffic</td>
</tr>
<tr>
<td>High frequencies</td>
<td>More and more high frequencies</td>
</tr>
<tr>
<td>Short stop distance</td>
<td>Short and long stop distances</td>
</tr>
<tr>
<td>Regularity</td>
<td>Periodic or aperiodic timetables</td>
</tr>
<tr>
<td>Simple track layouts</td>
<td>Complex track layouts</td>
</tr>
<tr>
<td>Local line or network</td>
<td>Large networks</td>
</tr>
<tr>
<td>Closed environment</td>
<td>Open environment</td>
</tr>
<tr>
<td>Simple organizational structure</td>
<td>Many stakeholders</td>
</tr>
<tr>
<td>Single operator</td>
<td>Many train operators (including freight)</td>
</tr>
</tbody>
</table>
ATO over ETCS: Functional concept

ETCS Onboard

Subset 130
Supervision information

Speed profile

Subset 139
Traction & brake commands

Train

ETCS Trackside

Train

Track

Journey profile + Segment profile

Subset 126

Subset 132

Adjacent ATO Trackside

Subset 131

Traffic Management

Subset 130

Subset 131

Subset 132

Subset 139
ATO over ETCS: Functions

- Driving functions
- Timing point management
- Train door operation
- Dwell time management (countdown)
- Add/skip stopping point (updating Journey Profile)
- Hold train at stopping point (updating Journey Profile)
- Low adhesion management
- Reporting management (status information for monitoring)
ATO over ETCS: Driving functions

- **Timetable Speed Management (TTSM):** Optimal speeds to stop or pass on time in the most energy efficient way
- **Supervised Speed Envelope Management (SSEM):** Maximum speed respecting the ETCS speed limits
- **Automatic Train Stopping Management (ATSM):** Speed profile to stop the train accurately at the stopping points
- **ATO Traction/Brake Control:** output commands to drive the train
ATO over ETCS GoA 2 DMI (concept)
ATO over ETCS GoA 2 DMI (concept)

Motoring/braking status
- Coasting
- Motoring
- Braking

Distance left
- Distance to the next Stopping Point (m)
- 1250

Estimated arrival delay
- Estimated delay >= 1min
- 27
- 3m

Dwell time
- Dwell time remaining
- [s] > 0
- Train hold
- Dwell time remaining
- [s] > 1min
- Delayed departure
- 27
- H
- 3m
- 27

Stopping accuracy
- Undershoot stopping window
- Inside stopping window
- Overshoot stopping window

Skip stop
- Skip Stopping Point
- Inactive
- Requested by the driver
- Requested by ATO-TS
Digital Railway Traffic System Components

- Wireless Communication and Signalling
- Automatic Train Operation
- Intelligent Traffic Management
- Automated Timetabling
Macroscopic timetabling

Time-distance diagram for corridor Ut-Ehv

Station routing and platforming

Platform occupation diagram of scenario original with 114(s) buffer time

Microscopic timetabling

Blocking time diagram for route of train line 3500

Train trajectory optimization
Multi-objective timetabling

- Optimal timing
- Conflict-free track allocation
- Platform & route assignment

Energy-efficient speed profiles
Robustness
Stability

Tu Delft
Pareto optimality
Digital Railway Traffic System Components

- Wireless Communication and Signalling
- Automatic Train Operation
- Intelligent Traffic Management
- Automated Timetabling
Manual driving (GoA 1)

Legend:
- Vital
- Non-vital
Manual driving with Connected DAS (GoA 1)

DAS: Driver Advisory System
TMS: Traffic Management System

Legend: Vital | Non-vital
Driverless/Unattended operation (GoA 3-4)

Interlocking
- Route setting
- Route
- Stations/junctions

Radio Block Centre
- Targets
- Route setting

TMS
- TMS
- Train position
- Out of bandwidth
- Small deviations
- Speed control
- Speed supervision

ATO
- Trajectory Generation
- Trajectory Tracking
- Train position
- Out of bandwidth
- Small deviations
- Speed control
- Speed supervision

Train
- Movement Authority
- ATP
- Train detection
- Track-clear Detection

Legend:
- Vital
- Non-vital

TMS: Traffic Management System
Adaptive train trajectory optimization

Optimal intercity trajectory

Optimal intercity trajectory following severely delayed local train
Train-centric signalling

ETCS Level 3 (moving block) signalling

Virtual Coupling signalling
Digital Railway Traffic System Components

- Wireless Communication and Signalling
- Automatic Train Operation
- Intelligent Traffic Management
- Automated Timetabling
Intelligent railway traffic management systems (TMS)

- **Track**
  - Route Setting
  - Train Detection

- **TMS**
  - Real-Time Timetable
  - Monitoring
  - Prediction
  - Conflict Detection
  - Conflict Resolution
  - Disruption Detection
  - Disruption Rescheduling

- **Train**
  - C-DAS/ATO
  - Train Positioning

- **Passengers**
  - Travel Information
  - Travel Choice
Digital railway traffic system evolution

- Fully automated trains (GoA4)
- Driverless Train Operation (GoA3)
- Automated Disruption Management
- Semi-automatic Train Operation (GoA2)
- Intelligent railway traffic management
- Connected Driver Advisory Systems (GoA1 with C-DAS)
- Automated timetabling
- Virtual Coupling

Performance

2019 Digitalisation
Takeaway message

Railway operations research must provide the tools for

• Automated timetabling
• Intelligent traffic management
• Automatic train operation
• Advanced signalling

in digital railway traffic systems to realize a systems jump in railway transport performance