Intelligent Railway Traffic Management

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Traffic management process

1. Monitoring and information
   - Infrastructure
   - Train operations and crews
   - Passengers
   - Freight
2. Detection and analysis of irregularities, failures and accidents
3. Development, evaluation and selection of dispatching measures
   - track occupation & clearance, signals, switches
   - train #/location/speed, arrival/depart. times
   - volumes, flows, behaviour, safety
   - weight, (temperature), security
   - train delay start/end times/locations, conflicts
   - failure classification, MTBF, MTTR
   - accident #/location, causes and severity
   - type and impact assessment of dispatching measures
   - conflict resolution, rescheduling
Monitoring system

Function
• Registration of the amount and cause of increased delays
  • between two successive scheduled events (arrival, departure, passage)

Working
• Receive and store train delays
• Compute delay jumps
• Display train events with delay jump of 3 min or more to signalmen
• Signalmen add cause and responsible party using a classification tree
• Approval by responsible party, verification, authorization

Drawbacks
• Train delays are updated when passing at station signals
  - cause of a delay is (much) earlier, past information no more available
• Delays-to-be-explained pile up during disrupted operations
  - main task of signalman: route setting and informing train drivers
  - registration follows after a hectic period
  - Information from driver calls in case of incidents often unclear
• Subjectivity: signalman may be the cause of delays, biased opinion
Traffic control screens DB
Online train graphs Deutsche Bahn

Train category and number
Past time
Actual time line
Prediction
Delay [min]

Track layout
Centralized Traffic Control

- Traditional evaluation of operational situation
  - Based on data collected and displayed on track layout
  - In dispatcher’s mind based on expert knowledge
  - Static time-distance diagrams

- Computer support
  - Visualisation of current train positions by train describers in interlocking areas
  - Automatic route setting (ARS) based on train describers
  - Dynamic time-distance diagrams (historical and future train paths)

- Intelligent decision support needed
  - Automatic traffic state prediction and train conflict detection
  - (Semi-)automatic route conflict resolution
Current rescheduling practice

Basic rules applied:
1. If there is a route conflict between trains running to the same track, the planned order is maintained;
2. If there is a route conflict between trains running to different tracks, the train that has claimed its route first, will go first (FCFS);
3. When trains are outside a predefined time-window (usually 3 or 5 minutes) the dispatcher may act according to his knowledge, experience and a list of what-if scenarios.
Current traffic management drawbacks

- Computer support often limited to graphical interfaces and automatic route setting systems;
- Dispatchers usually do not have precise information of the future evolution of train traffic and the chosen actions may be suboptimal;
- The delay propagation is unpredictable by traffic controllers, especially in case of complex rail networks, high density traffic, severe disturbances;
- Traffic controllers/dispatchers act reactively and not proactively;
- Predetermined rules/disruption programs do not consider actual situation.
Essential requirements for railway perturbation management

- Actual train position, travel direction and speed
- Train weight and braking rate
- Dynamic train occupancy (number of passengers)
- Dynamic platform track occupation and scheduled train connections
- Reliable prediction of headway and route conflicts
- Accurate prediction of running times and delays (advisory speed)
- Train circulation and crew rotation plans
- Impact assessment of dispatching measures
Automatic conflict detection tool (TU Delft): Blocking time diagram

Red blocks: ⇒ Route conflict
Intelligent Rescheduling (1)

- **Essentials**
  1. Conflict free timetable
  2. Real-time data communication
     - infrastructure use (signals, track occupation/clearance, route setup/release) and
     - train operation (length, position, speed, delay, accel./braking, weight)
  3. Automatic headway and route conflict detection/resolution
  4. On-line decision support for traffic controllers/dispatching
  5. Dynamic advisory speeds

- **Conflict resolution measures**
  1. Retiming (holding, extension of running time)
  2. Reordering (relocation/provision of passing stops for overtaking)
  3. Rerouting (alternative local routes and alternative lines)
  4. Cancelling trains
Intelligent Rescheduling (2)

• Objectives
  ➢ Minimize overall train delays
  ➢ Minimize weighted delays (trains, passengers)
  ➢ Minimize maximum train delay
  ➢ Minimize total knock-on train delays
  ➢ Minimize delay survival period
  ➢ Ensure maximum number of line connections
  ➢ Maintain maximum circulation plans of rolling stock and crews
  ➢ Minimize number of extra train services in case of disruption

• Priority rules
  1. Emergency trains
  2. Premium (high-speed) passenger trains
  3. Long-distance (Intercity) trains
  4. Premium freight trains
  5. Express regional trains
  6. Regional trains
  7. Other freight trains
Intelligent Rescheduling (3)

**Performance** depends on
- Amount/increase of measured/expected train delay
- Cause of primary (and consecutive) delay and disruption
- Location where the event or delay happened
- Time of the day
- Passengers involved
- Traffic intensity and density
- Rerouting alternatives.

**Traffic management policy**
- **Event driven**
- **Time driven**
- **Hybrid**

**Complexity**
- Network topology
- Time restriction/urgency
- Accuracy of model
- Computational effort
Feedforward traffic management information

- **Dispatcher support**
  - Generation of rescheduling options
  - Fast performance evaluation of rescheduling measures
  - Prediction of incident duration and fading-out time
  - Selection of adapted schedule (timetable, rolling stock, crews)
  - Prediction of running, arrival and departure times
  - (Semi-)automatic conflict resolution

- **Driver support**
  - Holding, advisory train speed
  - Adaptation of train circulation and crews rooster

- **Customer support**
  - Update of arrival/departure/transfer information
Running time prediction in case of delays
Percentiles of process times are computed based on historical data:
- Sum of running times over route segments (outbound route – open track block sections – inbound route)
- Dwell times
- Headway times between similar train pairs at conflict points
- Transfer connection times between same trains

Running and dwell times are updated every 10 – 30 s based on actual train positions and delays.

Simple model can be extended by clustering historical data and classifying train runs according to:
- Time of day
- Rolling-stock type
- Weather
- Delay
Change of signal aspects and track occupation/clearance times explain train movements

A. Following

B. Merging

C. Crossing
Validation of short-term prediction model (Kecman, 2014)

- Determination of the prediction time horizon (e.g. 20 (30) min.)
- Randomly selected 50% of available track occupation data used for calculation of arc weights
- Other 50% of empirical data used for model validation such that event times later than time horizon are computed
- Running order of trains in first instance as scheduled (input)
- Delay propagation algorithm runs backward in time through predecessor events
- Intermediate scheduled departure times used as constraints
Shortcomings of microscopic simulation models for real-time rescheduling

- Offline input data processing from signalling and safety systems
- Difficult tuning of rolling stock dynamics, especially concerning accurate train acceleration, distance, speed changes and braking
- Difficult network synchronization of simulation run output (train positions, speeds, knock-on delays); intractable for large networks
- Offline (multiple) simulation of train movements and delay propagation per corridor at high computation speed (>1/60)
- Complex impact assessment of simulation output for (alternative) rescheduling measures

hybrid/integrated (micro-macro transformation) models necessary!
Integrated micro–macro approach to robust railway timetabling (Besinovic et al. 2016)

Micro to macro
- Select timetabling points (stations/junctions)
- Aggregate running and dwell times
- Exploit given running time supplements
- IP node packing model to find feasible and robust timetable at network scale
- Objectives: Minimize travel times/train cancellations/extended transfer times/delay propagation

Macro back to micro
- Generate operational speed profiles
- Estimate track capacity consumption
- Detect/remove headway conflicts
EU funded research project
ON-TIME 2011-2014 (outline)

• Research team

• Deliverables

❖ WP 3 Development of robust and resilient timetables

❖ WP 4 Methods for real-time management of operations

❖ WP 6 Driving Advisory System

❖ WP 7 Demonstration simulation of real-time traffic management

http://www.ontime-project.eu
ON-TIME: From Science to Practice
Different test cases around Europe

East Coast Main Line (UK)
- Sandy
- Bishop's Stortford
- Bishops Stortford
- Hitchin
- Stevenage
- Luton
- Dunstable
- Milton Keynes
- Aylesbury
- London
- King's Cross

Utrecht-Eindhoven Nijmegen-Tilburg (NL)
- Hertford North
- Bayford
- Crews Hill
- Gordon Hill
- Enfield Chase
- Orange Park
- Winchmore Hill
- Palmers Green
- Wood Green North Jn
- Alexandra Palace
- Harringay
- Timpson Park
- Drayton Park
- Highgate
- Highbury & Islington
- Essex Road
- Old Street

Iron Ore line (SE)
- Abisko
- Kruuna
- Rätsi
- Skapavallen
- Kaskullstull
- Gällivare
- Border
- Luleå

→ Real-time video
ON-TIME: From Science to Practice
Demonstration
Conclusions (1)

**Offline** traffic analysis tool based on train describer records for improving timetable quality and efficiency

- Statistical analysis of train diagram variation (performance bandwidth)
- Automatic estimation of realized arrival and departure delays at stations with accuracy $\approx 5$ seconds
- Automatic recognition of historical route conflict locations and probabilities
- Distinct analysis of hindered/unhindered train running time and primary/consecutive delay distributions
- Tuning of scheduled running time allowance and buffer times
Conclusions (2)

**Online decision support implementation**

- Open track train position and actual train speed monitoring
- Automatic computation and visualization of headways, blocking times and (consecutive) train delays in case of conflicts
- Accurate train running time and dwell time information
- Computation and communication of advisory train speed to drivers
- Alleviation of traffic controllers’ work from routine work (Automatic Train Regulation)
- Impact assessment of proactive conflict resolution measures in case of incidents/disruptions
- Reliable prediction of arrival/departure/transfer connection delays for passengers
Literature

- Daamen, W., Goverde, R.M.P., Hansen, I.A. (2009), Non-discriminatory Automatic Registration of Knock-On Train Delays, *Networks and Spatial Economics, 9*(1), 47-61
- Hansen, I.A. (2009), Introduction, Guest editorial Special Issue on Railway Network Optimization, *Networks and Spatial Economics, 9*(1), 1-5
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- Stevenage
- Luton
- Watton-at-Stone
- Ashwell & Morden
- Baldock
- Letchworth
- Cambridge
- Cambridge Jn
- Hertford
- Hertford North
- Bayford
- Cuffley
- Crews Hill
- Gordon Hill
- Enfield Chase
- Orange Park
- Winchmore Hill
- Palmers Green
- Wood Green North Jn
- Alexandra Palace
- Harringey
- Finsbury Park
- Tottenham
- Drayton Park
- Highbury & Islington
- Essex Road
- Old Street
- London
- King's Cross

Utrecht-Eindhoven
Nijmegen-Tilburg (NL)

Iron Ore line (SE)

Real-time video

TU Delft
ON-TIME: From Science to Practice

Human Machine Interface

- Developed by Ansaldo STS
- Enables optimal resolution of route conflicts subject to infrastructure, safety, rolling stock and human constraints
- Interaction with disruption handling of railway undertaking
Results from the ON-TIME project

- The project ON-TIME has developed algorithms and tools for robust timetabling and real-time traffic management support into practice
- An open-loop strategy already improves train operations’ performance
- A closed-loop control strongly increase traffic resilience especially for shorter rescheduling intervals and longer prediction horizons
- Simulation tests prove the effectiveness of automatic real-time rescheduling on railway traffic performance in case of disturbance
- Tests over railway networks in different countries proved the applicability of the concept into real life

http://www.ontime-project.eu
### Appendix: Classification of railway (re)scheduling approaches

**Macroscopic models**
- A. Time-distance diagram (linear)
- B. Mathematical programming
- C. Blocking-time diagram

**Microscopic models**
- 1. Graphical
- 2. Analytical
- 3. Simulation

**Deterministic**
- Line
- Station

**Stochastic**
- Network
(Re-)scheduling decision support models

- **Macroscopic models**
  - Mathematical scheduling optimisation models (PESP)
    - Linear programming (Liebchen, 2006)
    - Constraint propagation (Kroon et al. 2008)
  - Timed Event Graph (PETER; Goverde, 2007, 2010)
  - Alternative Graph (aggregated; Kecman et al., 2012)

- **Microscopic models**
  - Asynchronous simulation (Gröger, 2004, Jacobs, 2008)
  - Synchronous simulation (RailSys, OpenTrack)
  - Constraint propagation (Rodriguez, 2007)
  - Alternative Graph (ROMA; D’Ariano, 2008; Corman, 2010)
  - Resource-Tree Conflict Graph (Caimi et al., 2011)

- **Micro-macro transformation models** (Schlechte et al., 2011; Besinovic et al., 2016)