Intelligent Railway Traffic Management

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13-7-2017

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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)

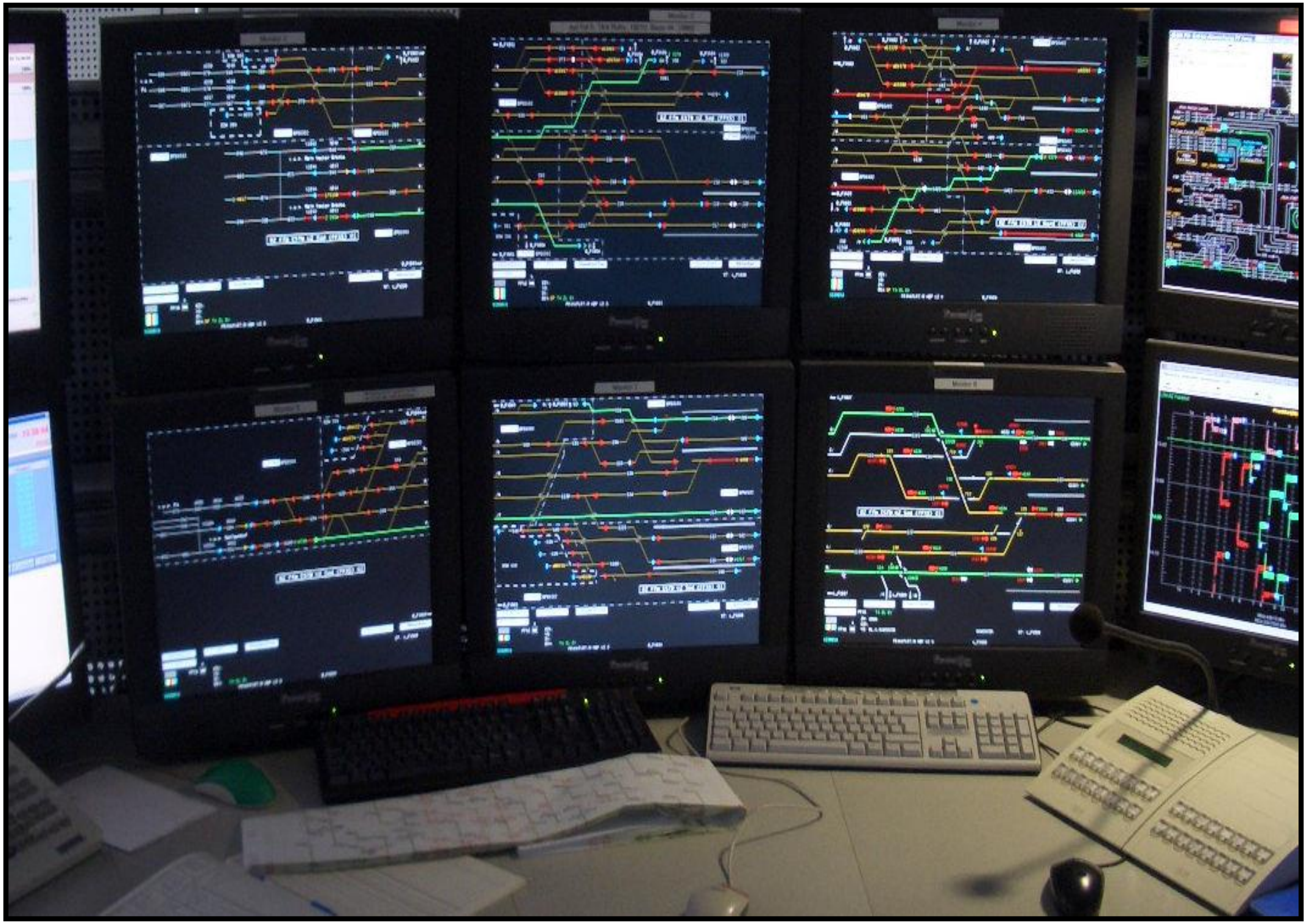
Working

- 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



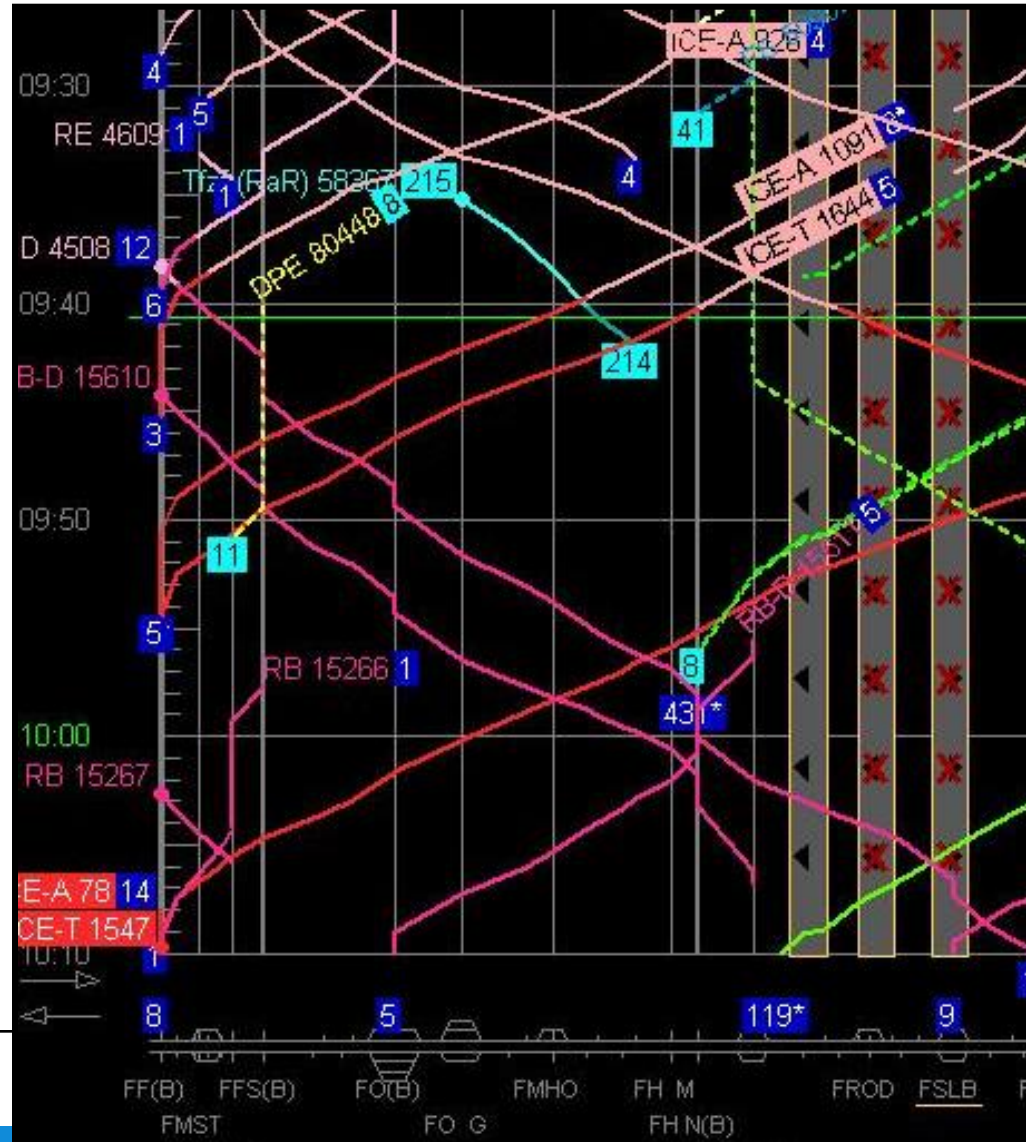
Online train graphs Deutsche Bahn

Train category and number

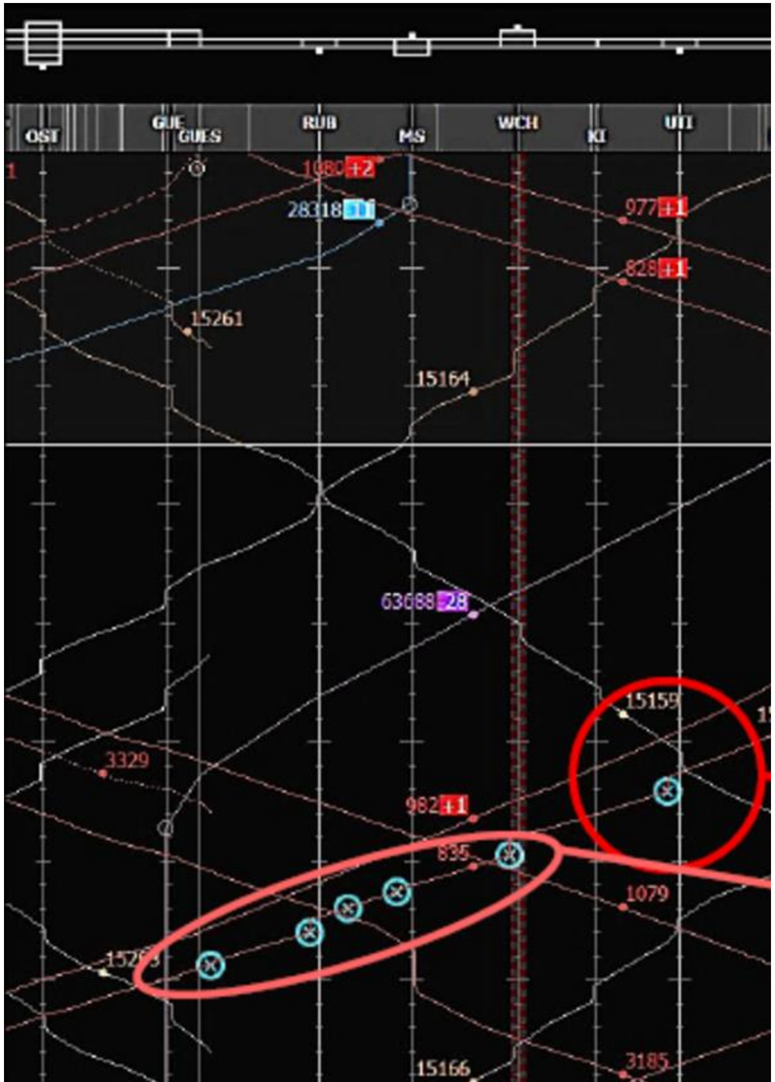
Past time
Actual time line
Prediction

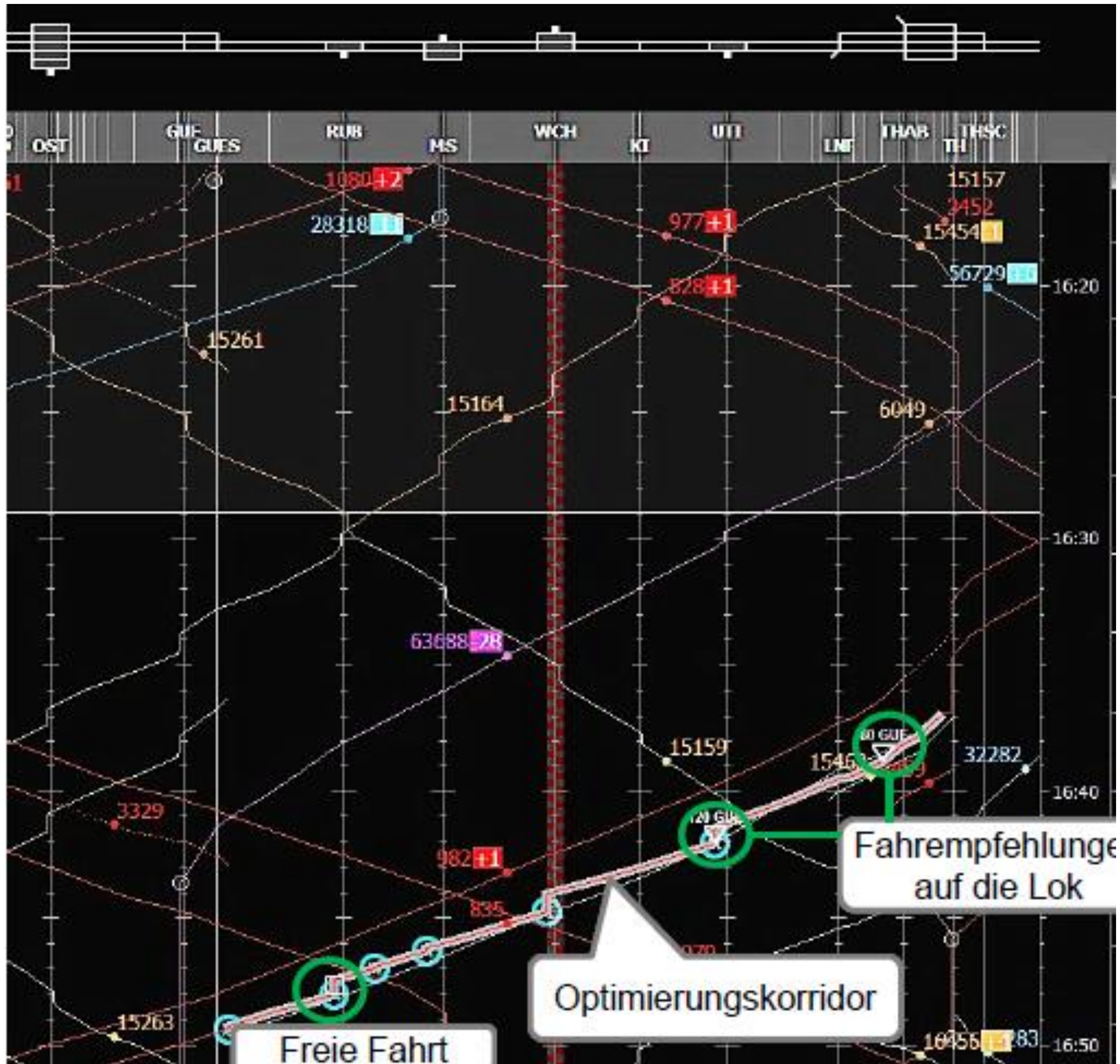
Delay [min]

Track layout



Automatic conflict recognition/speed adaptation RCS SBB https://www.sbbrcs.ch/en/family/rcs-dispo/





Proceed Compensation area Speed advice

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.

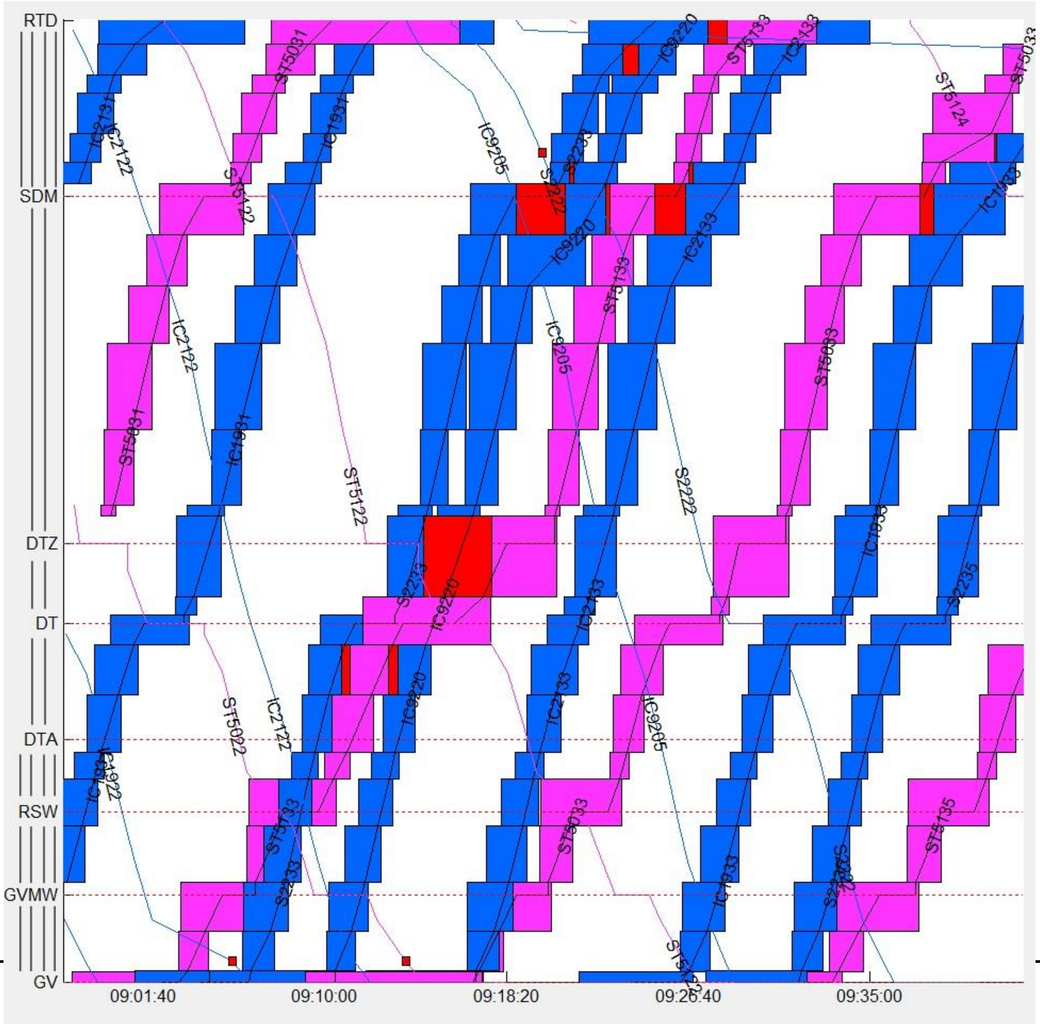
Current traffic management drawbacks

- 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 sub-optimal;
- 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**

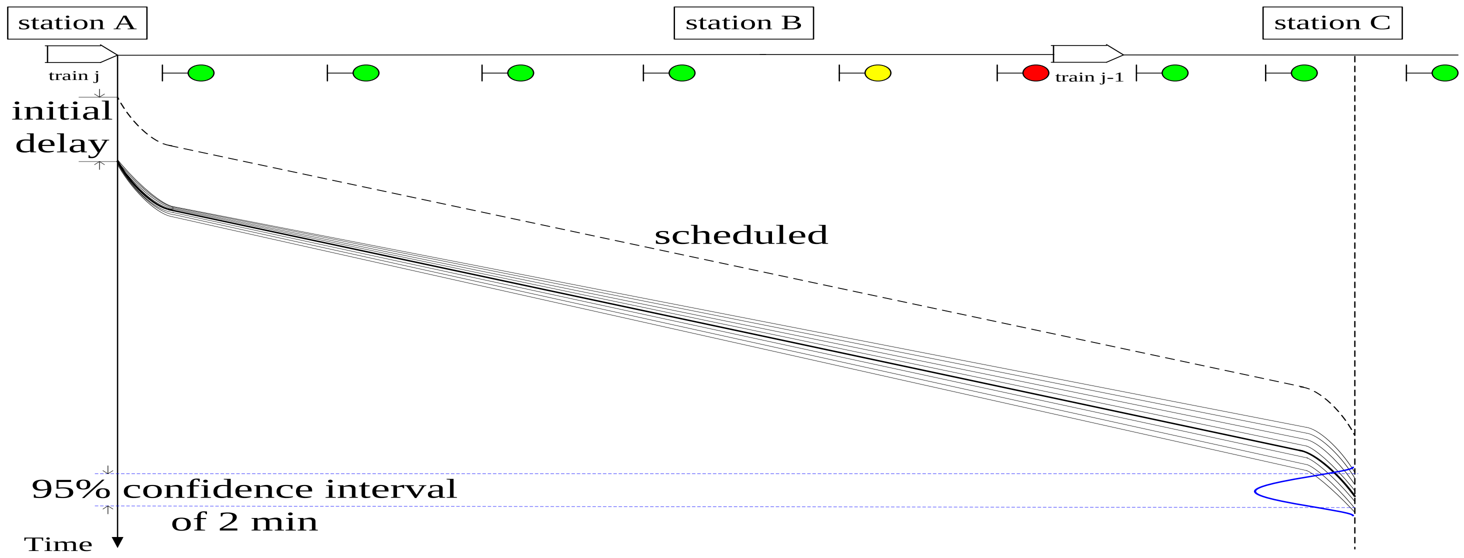
Complexity

- 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

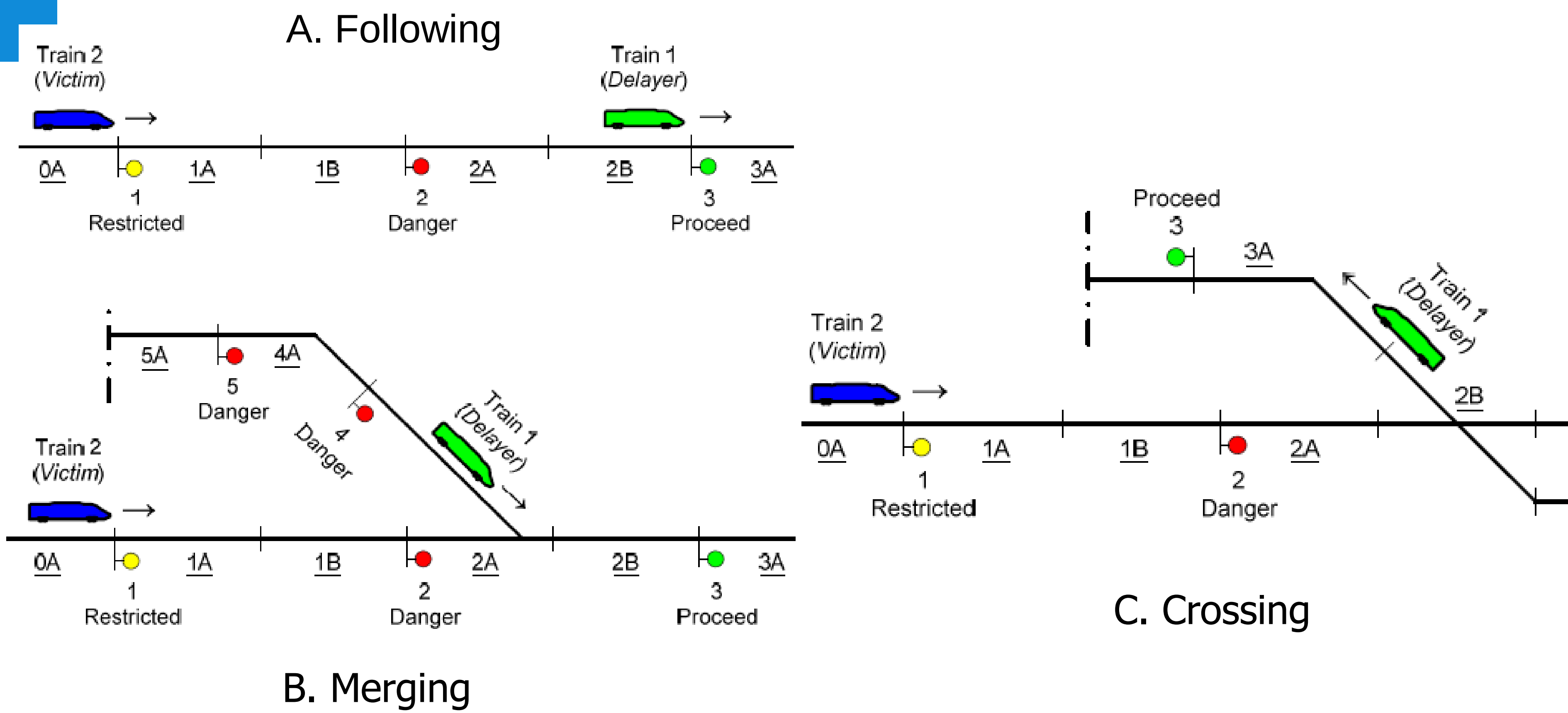
Running time prediction in case of delays



Short term prediction model (TU Delft)

- 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



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!

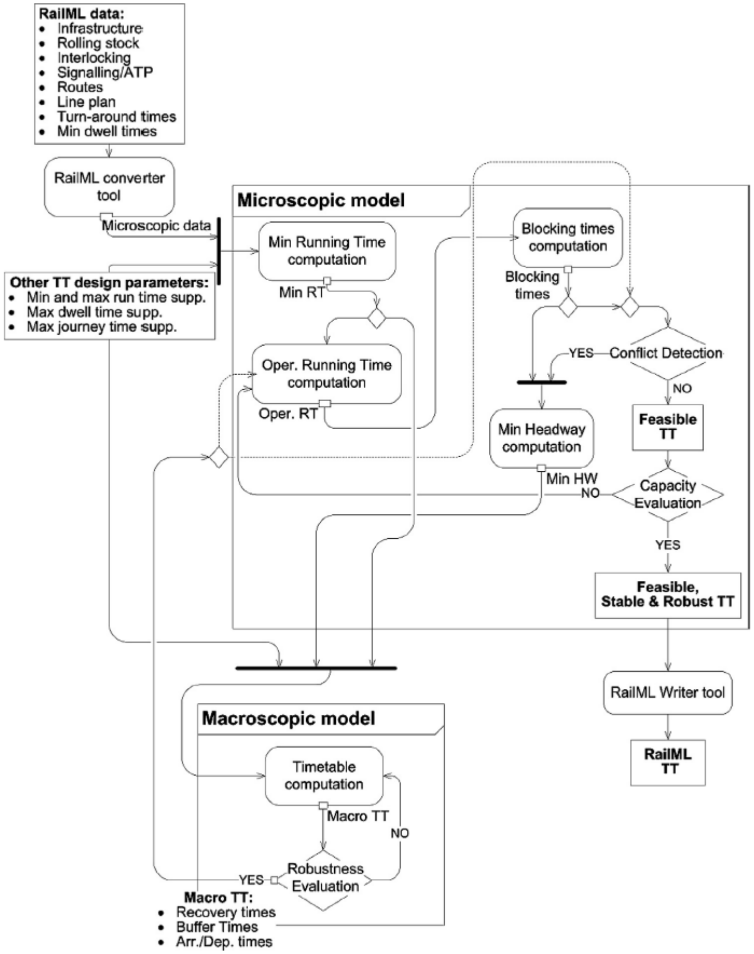
Integrated micro–macro approach to robust railway timetabling (Besinovic et al. 2016)

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

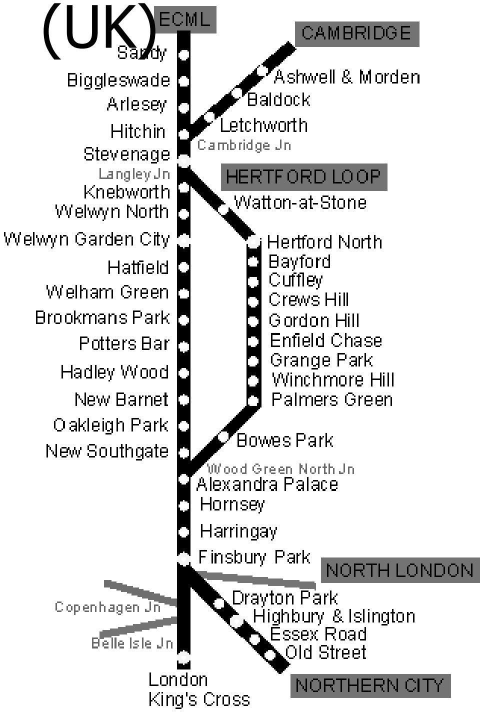
❖ WP 6 Driving Advisory System

❖ WP 7 Demonstration simulation of real-time traffic management

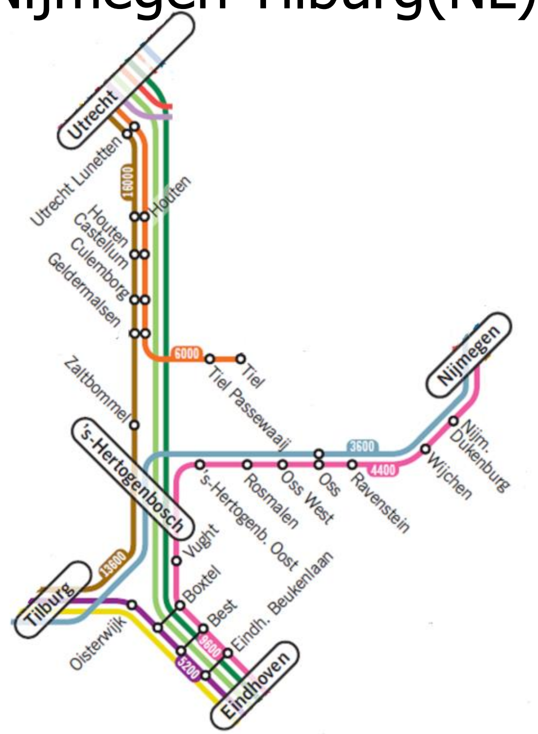
ON-TIME: From Science to Practice

Different test cases around Europe

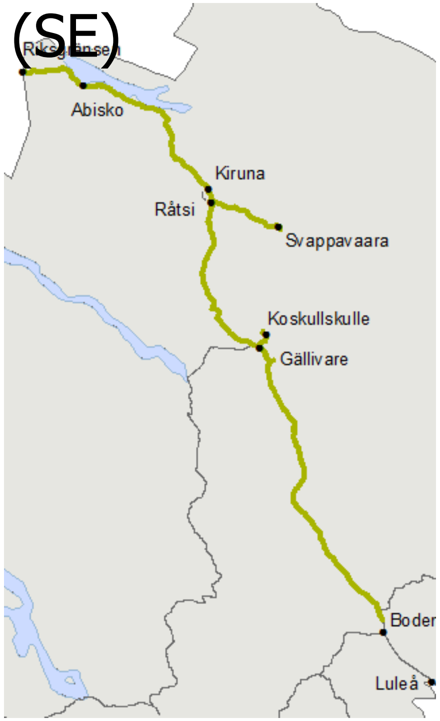
East Coast Main Line (UK)



Utrecht-Eindhoven Nijmegen-Tilburg(NL)



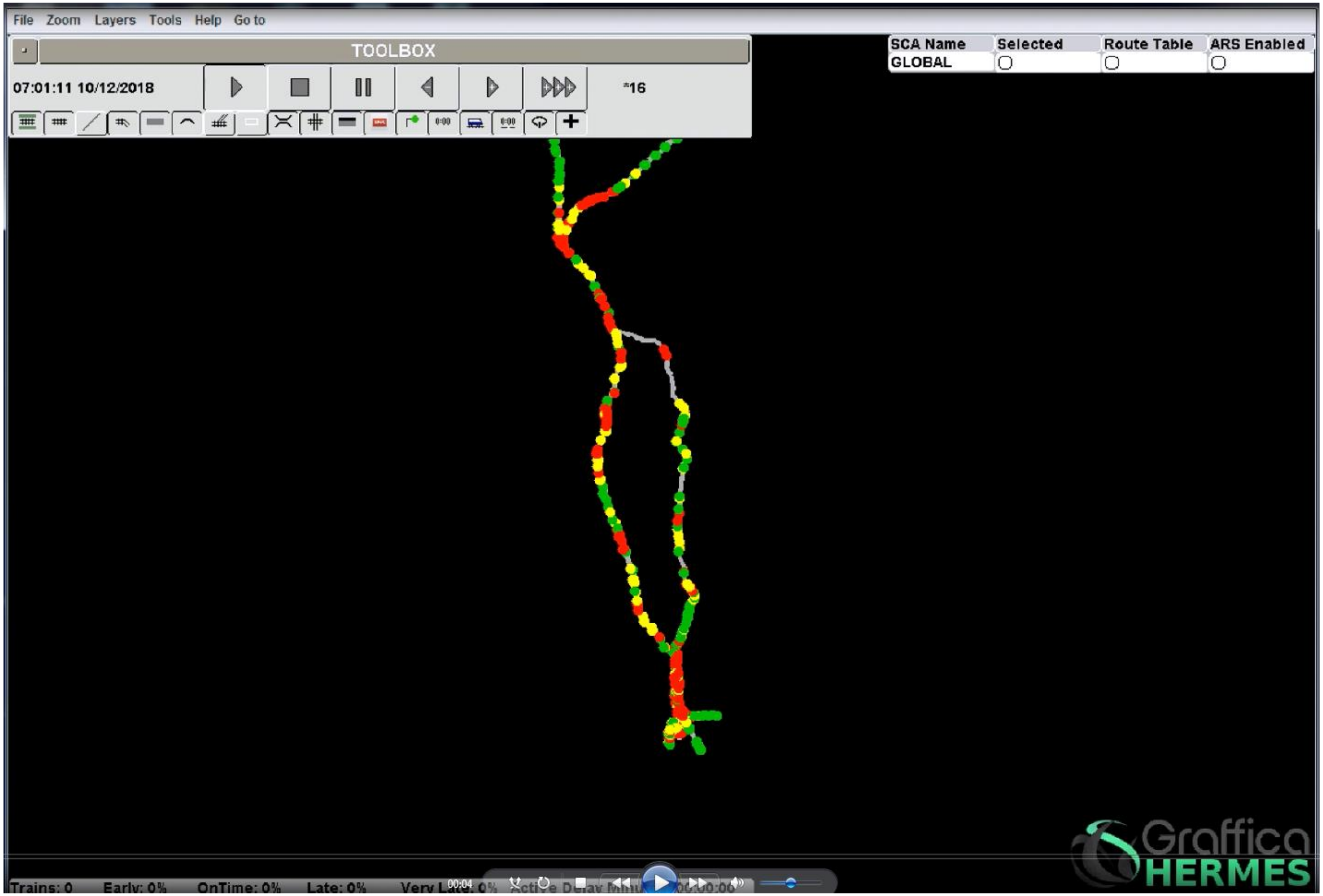
Iron Ore line (SE)



Real-time video

TU Delft

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 ≈ 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

- Besinovic,N., Goverde, R.M.P., Quaglietta, E., Roberti, R. (2016), An integrated micro–macro approach to robust railway timetabling, *Transportation Research Part B,* 87, 14-32
- Corman, F., D'Ariano, A., Pacciarelli, D., Pranzo, M. (2010), A tabu search algorithm for rerouting trains during rail operations, *Transportation Research Part B,* 44(1), 175-192
- 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
- D'Ariano, A. (2008), Improving Real-Time Train Dispatching. Models, Algorithms and Applications, PhD thesis, Delft University of Technology
- D'Ariano, A., Pranzo. M., Hansen, I.A. (2007), Conflict resolution and train speed coordination for solving real-time timetable perturbations, *IEEE Transaction On Intelligent Transportation Systems*, 8/2, 208-222
- Goverde, R.M.P., Meng, L. (2012), Advanced monitoring and management information of railway operations, *Journal of Rail Transport Planning & Management,* 1(2), 69-79
- Goverde, R.M.P. (2010), A delay propagation algorithm for large-scale railway networks, *Transportation Research Part E,* 18(3), 269-287
- Goverde, R.M.P. (2007), Railway timetable stability analysis using max-plus system theory, *Transportation Research Part B,* 41, 179-201
- Hansen, I.A. (2009), Introduction, Guest editorial Special Issue on Railway Network Optimization, *Networks and Spatial Economics*, 9(1), 1-5
- Hansen, I.A., Pachl, J. (2014), Railway Timetabling and Operations, Hamburg: Eurailpress
- Kecman P, Goverde R.M.P. (2014), Online data-driven adaptive prediction of train event times, *IEEE Transactions on Intelligent Transportation Systems*, Vol. 16(1), 465-474

TUDelft

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- Research team
- Deliverables

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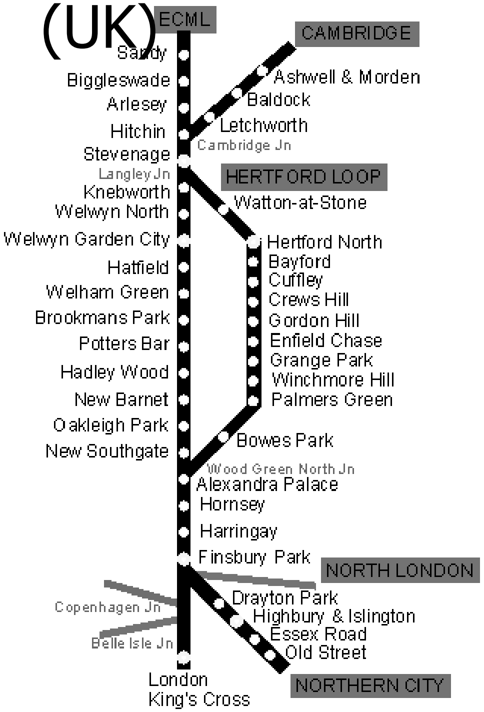

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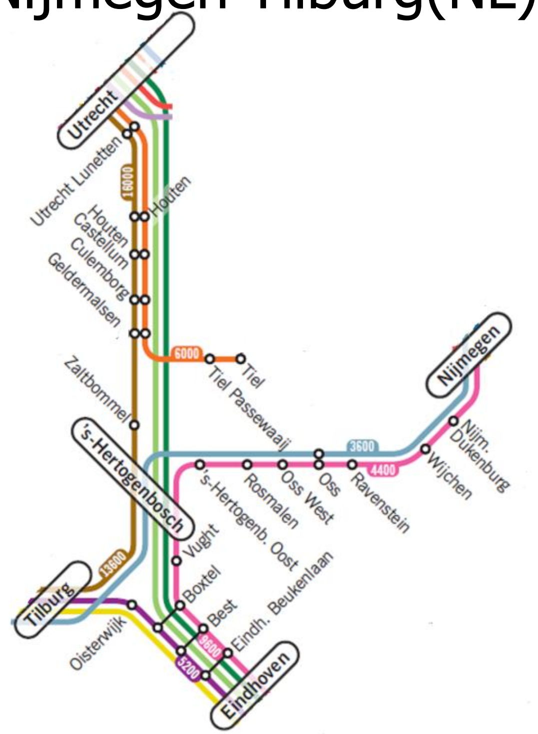

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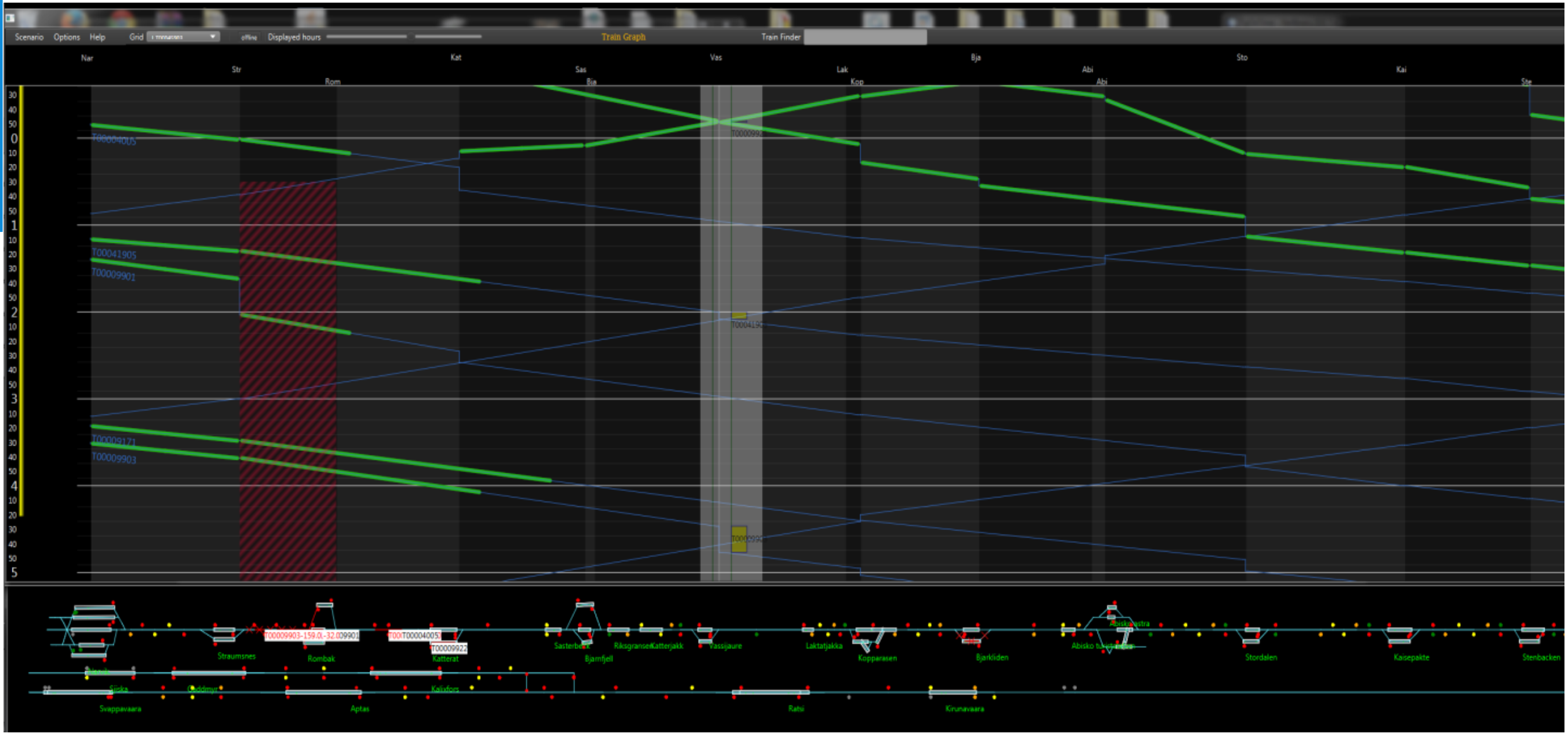
ON-TIME: From Science to Practice

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)	1. Graphical	Deterministic	- Line
	B. Mathematical programming	2. Analytical		- Station
Microscopic models	C. Blocking-time diagram	3. Simulation	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)