An integrated framework for real-time railway traffic management

Results from the EU FP7 project ON-TIME

4 June 2015

Dr. Rob M.P. Goverde
Department of Transport and Planning
Delft University of Technology
The Netherlands
r.m.p.goverde@tudelft.nl
Outline

- ON-TIME
- Real-time traffic management
- Framework
- Traffic management modules
- Service-oriented architecture
- Demonstration
- Conclusions
ON-TIME

Project overview

• Optimal Networks for Train Integration Management across Europe
• Funded by the EU 7th Framework Programme
• Duration 2011-2014 (3 years)
• 19 partners

An integrated framework for real-time railway traffic management
ON-TIME

Project overview

High-level aim
• Increased capacity and decreased delays for passenger and freight

Innovations
1. Standardized definitions and methods
2. Improved methods for timetable construction
3. Algorithms for traffic management of minor perturbations
4. Decision support for large disruptions
5. Centrally guided train operation
6. Standardized ICT architecture

Demonstrations
• East-Coast Main Line (UK)
• Iron Ore Line (SE/NO)
• Subnetwork Utrecht-Eindhoven / Nijmegen-Tilburg (NL)
ON-TIME

Project overview

High-level aim
• Increased capacity and decreased delays for passenger and freight

Innovations
1. Standardized definitions and methods
2. Improved methods for timetable construction
3. Algorithms for traffic management of minor perturbations
4. Decision support for large disruptions
5. Centrally guided train operation
6. Standardized ICT architecture

Demonstrations
• East-Coast Main Line (UK)
• Iron Ore Line (SE/NO)
• Subnetwork Utrecht-Eindhoven / Nijmegen-Tilburg (NL)
Real-time traffic management

**Algorithms and architecture**

**Problem**
- Real-time perturbation management of small delays

**Assumptions**
- No interaction with Railway Undertaking necessary
- Aiming at automatic decisions

**Approach**
- Closed-loop conflict detection and resolution (CDR)
- Conflict resolution measures
  - Reorder trains
  - Reroute trains
  - Retime trains
  - Cancel or add non-commercial (operational) stops
- Embed CDR algorithms in ICT environment

An integrated framework for real-time railway traffic management
Framework for real-time railway traffic management

Traffic State Monitoring (TSM)

Traffic State Prediction (TSP)

Conflict Detection & Resolution (CDR)

Connection Conflict Detection & Resolution (CCDR)

Are connections changed?

YES

NO

Web-service

RTTP

Connection list

Web-service

Driver Advisory System (DAS)

Train Path Envelope Computation (TPEC)

Automatic Route Setting (ARS)

Web-service

Human-Machine Interface (HMI)

Web-service

Perturbation Management Module (PMM)

Web-service

Web-service

HERMES/Real Traffic

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Conflict Detection & Resolution (CDR)

Benchmarks

• Implemented CDR approaches
  - ROMA (TU Delft)
    - Minimization of maximum consecutive delay over Alternative Graphs
    - B&B for rescheduling plus tabu search for rerouting
  - RECIFE (IFSTTAR)
    - Minimization of total delay by mixed-integer linear programming
    - C-PLEX
• Control measures
  - Reordering
  - Rerouting
  - Retiming
• Algorithms adapted for online use with RailML/XML exchange data
• Result: Real-Time Traffic Plan
Real-Time Traffic Plan (RTTP)

Microscopic description of traffic execution

- Routing: which **routes** trains will take over network
- Scheduling: which **order** and **time** trains will pass over track sections

<table>
<thead>
<tr>
<th>Train 1001</th>
<th>Train 801</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route</td>
<td>Section</td>
</tr>
<tr>
<td>O-A</td>
<td>TS1</td>
</tr>
<tr>
<td>A-C</td>
<td>TS2</td>
</tr>
<tr>
<td></td>
<td>TS4</td>
</tr>
<tr>
<td>C-D</td>
<td>TS5</td>
</tr>
<tr>
<td>D-E</td>
<td>TS6</td>
</tr>
</tbody>
</table>

**Infrastructure view**

<table>
<thead>
<tr>
<th></th>
<th>TS1</th>
<th>TS2</th>
<th>TS3</th>
<th>TS4</th>
<th>TS5</th>
<th>TS6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order</td>
<td>1001</td>
<td>1001</td>
<td>801</td>
<td>1001</td>
<td>801</td>
<td>801</td>
</tr>
<tr>
<td>1001</td>
<td>1001</td>
<td>801</td>
<td>1001</td>
<td>801</td>
<td>801</td>
<td>1001</td>
</tr>
<tr>
<td>801</td>
<td>801</td>
<td>1001</td>
<td>1001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An integrated framework for real-time railway traffic management
Real-Time Traffic Plan (RTTP)

XML exchange format

```xml
<rTTP>
  <rTTPTrainView>
    <rTTPForSingleTrain trainId="T00004005">
      <tDSectionOccupation tDSectionID="TDS00120" trainID="T00004005" occupationStart="01:02:00 CEST" routeId="routeR00095"/>
      <tDSectionOccupation tDSectionID="TDS00112" trainID="T00004005" occupationStart="01:08:37 CEST" routeId="routeR00081"/>
      <tDSectionOccupation tDSectionID="TDS00111" trainID="T00004005" occupationStart="01:08:59 CEST" routeId="routeR00081"/>
    </rTTPForSingleTrain>
  </rTTPTrainView>
  <rTTPInfrastructureView>
    <rTTPForSingleTDSection tDSectionId="TDS00081">
      <tDSectionOccupation tDSectionID="TDS00081" trainID="T00009926B" occupationStart="01:02:07 CEST" routeId="routeR00050"/>
      <tDSectionOccupation tDSectionID="TDS00081" trainID="T00009921B" occupationStart="01:39:49 CEST" routeId="routeR00052"/>
      <tDSectionOccupation tDSectionID="TDS00081" trainID="T00004005" occupationStart="01:57:58 CEST" routeId="routeR00052"/>
    </rTTPForSingleTDSection>
  </rTTPInfrastructureView>
</rTTP>
```
Human-Machine Interface (HMI)

Train Graph and Train Describer
Automatic Route Setting (ARS)

Automatic execution of RTTP

Automatic Block Signals

Start signal of route R0

Time when route R0 should be set

Route setting and driver reaction time $T_{RD}$

Signal sighting distance

$S2 \quad S1 \quad S0$

$t_0 \quad t_1 \quad t_2 \quad t_5$
Train Path Envelope (TPE)

Interface between RTTP and train DAS

Train Path Envelope

- Sequence of **target windows or points** for train
  - Position
  - Earliest and latest time at position
  - Maximal and minimal speed at position

- Based on time allowances in RTTP

```xml
  <corridor train_service_id="S3521" timestamp="10/12/2018 07:28:20">
    <corridorWindow position_id="startd15e30_Ut_Gdm40" time_min="90,00" time_max="90,00"
      vel_min="0" vel_max="50" nonCommercialStop="false" reason="reason: StartOfEnvelope" />
    <corridorWindow position_id="TDS0_Ht0026d15e1562_41080" time_min="1243,11" time_max="6901,83"
      vel_min="20" vel_max="80" nonCommercialStop="false" reason="reason: trainBeforeLeaves" />
    <corridorWindow position_id="TDS0_Ht0038d15e911_2205" time_min="1263,41" time_max="6957,06"
      vel_min="40" vel_max="120" nonCommercialStop="false" reason="reason: hostTrainGoSlower" />
    <corridorWindow position_id="TDS0_NHt111d15e1433_41090" time_min="1291,26" time_max="7023,06"
      vel_min="40" vel_max="120" nonCommercialStop="false" reason="reason: endOfEnvelope" />
  </corridor>
</tpe>
```
Driver Advisory System (DAS)

Centrally Guided Train Operation

- Computation of energy-efficient train trajectory within TPE
- Generation of advice
- Display of advice

An integrated framework for real-time railway traffic management
An integrated framework for real-time railway traffic management

Traffic Prediction (TSP)

Conflict Detection & Resolution (CDR)

Traffic State Monitoring (TSM)

RTTP

Connection Conflict Det. & Res. (CCDR)

Are connections changed?

YES

NO

Web-service

Perturbation Management Module (PMM)

Human-Machine Interface (HMI)

Automatic Route Setting (ARS)

Train Path Envelope Computation (TPEC)

Driver Advisory System (DAS)

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service

Web-service
Service-oriented architecture (SOA)

Modules linked as subscriber/publisher of events

- REST web service interface between modules and architecture
- RabbitMQ message broker for routing event messages
- MongoDB non-relational database for storage of event messages
- RailML exchange format for static data
  - Infrastructure, timetable, rolling stock, interlocking
- XML exchange format for dynamic data
  - Current traffic state, RTTP, TPE, DAS advice

An integrated framework for real-time railway traffic management
Service-oriented architecture (SOA)

Real-time rolling-horizon closed-loop control

- Traffic continues during computations of TSM, TSP, CDR, HMI, ARS
- Prediction Horizon (PH, 1 hour) and Replanning Interval (RI, 2 min)

- TSM continuously receives track occupation events
- Each Replanning Interval
  - TSM publishes current traffic state (positions and speeds of all trains)
  - TSP computes traffic prediction over Prediction Horizon
  - CDR detects and resolves conflicts over Prediction Horizon in RTTP
  - HMI, ARS and TPEC subscribed to RTTP
  - TPEC computes Train Path Envelopes
  - DAS of all trains subscribed to TPE
- ARS sets routes as late as possible
- Infrastructure and trains operate according to RTTP by ARS and DAS
Service-oriented architecture (SOA)

Timing

Architecture Monitoring Prediction Conflict Resolution

TDSectionOccupation

CurrentTrafficState FutureTrafficState

FutureTrafficState

Time
An integrated framework for real-time railway traffic management
Service-oriented architecture (SOA)

An integrated framework for real-time railway traffic management
Demonstration
An integrated framework for real-time railway traffic management.

Traffic State Monitoring (TSM)

Traffic State Prediction (TSP)

Conflict Detection & Resolution (CDR)

Connection Conflict Detection & Resolution (CCDR)

Yes

Are connections changed?

NO

RTTP

Web-service

Perturbation Management Module (PMM)

Web-service

Connection list

Web-service

Auto Static Route Setting (ARS)

Train Path Envelope Computation (TPEC)

Driver Advisory System (DAS)

Human-Machine Interface (HMI)

Web-service

Traffic Prediction (RTTP)

Are connections changed?

YES

Connection list

Web-service

HERMES/Real Traffic
Demonstration

Iron Ore line Narvik-Svappavaara corridor

- Single track line 475 km long
- 20 meet-pass points and 31 interlocking areas
- Mixed traffic (passenger trains and 600/750 m long Iron Ore trains)
- Perturbation: Freight train 9904 Kiruna-Narvik 40 min departure delay
Demonstration

Simulation set-up

An integrated framework for real-time railway traffic management
Demonstration

Iron Ore line

CDR
• ROMA versus RECIFE
Demonstration

Iron Ore line: Quantitative Evaluation

- Scenario: 40 min delay train 9904 from Kiruna

**Without ON-TIME**

Resilience: reference scenario vs delay scenario

<table>
<thead>
<tr>
<th>Deviation area [h^2]</th>
<th>4:15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum delay [h:mm]</td>
<td>1:45</td>
</tr>
<tr>
<td>Settling time [h:mm]</td>
<td>3:50</td>
</tr>
</tbody>
</table>

**With ON-TIME (ROMA)**

Resilience: reference scenario vs delay scenario

<table>
<thead>
<tr>
<th>Deviation area [h^2]</th>
<th>3:45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum delay [h:mm]</td>
<td>1:15</td>
</tr>
<tr>
<td>Settling time [h:mm]</td>
<td>3:45</td>
</tr>
</tbody>
</table>
Demonstration

Video

Demonstration videos

- Iron Ore line (SE/NO)
  - Crossborder single-track line, mainly long freight trains
- East Coast Main Line (UK)
  - Busy corridor with many heterogeneous passenger trains
- Dutch Utrecht-Eindhoven / Nijmegen-Tilburg network (NL)
  - Network of busy corridors with transfer connections
Conclusions

Framework for real-time traffic management

• A modular automatic closed-loop real-time traffic management system has been developed and tested in a simulation environment
• An open flexible, scalable, distributed, service-oriented architecture has been developed for the rail domain
• Extensions to the RailML data format have been developed
• XML-standards have been defined for dynamic data exchange
• Modules, tools and experience are available for next steps of test and integration with real control systems

More information

• http://www.ontime-project.eu