Benchmarking and evaluation of railway operations performance

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Outline

- Motivation
- Quality of Service (QoS) framework
- QoS quantitative evaluation
- Example of application – ON-TIME project
- Conclusions and future work
Motivation

- Differing perspective depending on the stakeholder
- Evaluation of quantity and quality of operational behaviour
- Whole system approach
  - Decomposition of system into properties
  - Measure the effect of changing system properties, i.e., quantitative evaluation
Quality of Service framework

Key measures

KPIs

Railway system

System properties

Influencing factors

Railway system decomposition

Quantitative output

BCRRE

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The QoS framework broadly has 4 applications:

- Benchmarking of simulation tools
- Comparison of timetables or operational control systems
- Visualisation of delay propagation
- Linking of real operational data and microscopic simulation
QoSQE methodology

**Inputs**
- Scheduled event times
- Location / scenario specific information
- Key parameter benchmark values
- Observation event log from simulator

**Processing**
- QoSQE process

**Outputs**
- Benchmark of baseline simulation
- Numerical values of the key measures
- Visualisation of KPIs

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The full Quality of Service framework...
The full framework

Key measures

KPIs

Railway system

System properties

Influencing factors

QoS framework outline
QoS-QE performance indicators

Transport volume
- freight tonne km
- passenger km

Journey time
- journey time
- no transfer
- interchange time

Connectivity

Passenger comfort
- crowding

Resilience
- deviation area
- time to recover
- maximum deviation
- delays at destination
- station arrival delays

Punctuality

Energy

Resource usage
- crew usage
- rolling stock usage
- track usage

Railway system
TV key measures

**Transport volume**

- passenger seat km = number of km travelled \( \times \) number of seats available on the service
- freight tonne km = number of km travelled \( \times \) freight train cargo capacity in tonnes

total values for selected O-D pairs during time \( T \)

Railway system
JT key measures

Journey time

The *average journey time* [seconds] of all journeys that make scheduled stops at O and D, in that order
The average interchange time of all interchanges at I for journeys that both depart O and arrive at D during the simulation time T.
RS key measures

Resilience

Based on the system deviation measurement:
- maximum deviation during time period T [seconds]
- time to recover [seconds]
- deviation area [seconds^2]
PT key measures

**Punctuality**

At station S, during time period $T$, the sum of arrival delays to all services departing S during $T$

- at intermediate stations
- at terminal stations

Railway system
EG key measures

For a given O-D pair, the average energy consumed per service for all services that both depart from O and arrive at D during time period $T$.

Energy

Transport volume

Passenger km

Freight tonne km

Journey time

Journey time no transfer

Journey time interchange

Crowding

Maximum deviation

Deviation area

Time to recover delays at destination station

Arrival delays

Energy consumption

Crew usage

Rolling stock usage

Track usage

Resource usage

Railway system
RU key measures

Resource usage

RU1: track usage: *the average number of trains passing a point per hour* during time period $T$

RU2: rolling stock: *the total number of rolling stock units in use* during time period $T$
Example: ONTIME project

- Project aim: an improvement in capacity by reducing delays and improving traffic fluidity

- Evaluation and comparison of traffic management approaches
  - For minor perturbations
  - For major perturbations
QoSQE applied in ON-TIME

Benchmarking

Network, timetable, time period

Simulation

Comparison between simulation and schedule at service level

Evaluation

Timetable

Simulation

Simulation + real-time perturbation management method

Outputs

Key measure values

Visualisation of KPIs

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ONTIME case studies

- Iron Ore line, Sweden and Norway
- East Coast main line, UK
- Section of Dutch network, The Netherlands

- Minor perturbations
  - e.g. temporary speed restriction, signal failure
- Major perturbations
  - e.g. complete line blockage
ONTIME case studies

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  - e.g. complete line blockage
IOL simulator benchmarking

Comparison between timetabled and simulated event times for IOL simulation…
IOL simulator benchmarking

The chart illustrates the difference between timetabled and simulated departure times at various stations. The x-axis represents the timetabled train service indices, while the y-axis lists the stations. The chart indicates whether the timetabled time was logged in the simulation (gray circles) or matched the simulation (white circles). The color bar on the right indicates the difference in time, ranging from 1 to 1600 seconds.
IOL quantitative evaluation

Quantification of key measures…

1. Demonstration of resilience KPI
   - using in-built simulator logic only
2. Key measure results
   - using perturbation management algorithms
Resilience KPI

The graph illustrates the deviation over time for a resilience KPI. The y-axis represents the deviation in minutes, while the x-axis indicates time in hours. The peak deviation is marked, and the area under the curve represents the deviation area. The time to recover is also indicated on the graph.
Key measure results with perturbation management

Punctuality

![Graph showing total delay for different locations with FCFS, algorithm 1, and algorithm 2.](image-url)
Algorithm 1

Algorithm 2
## Summary of the other measures

<table>
<thead>
<tr>
<th>JT</th>
<th>O-D</th>
<th>Reference simulation</th>
<th>FCFS</th>
<th>Algorithm 1</th>
<th>Algorithm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean journey time [min]</td>
<td>Narvik - Bergfors</td>
<td>162.5 (100%)</td>
<td>205.0 (126%)</td>
<td>164.0 (101%)</td>
<td>165.6 (102%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RS</th>
<th>FCFS</th>
<th>Algorithm 1</th>
<th>Algorithm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation area [s²]</td>
<td>1.519e+08 (100%)</td>
<td>1.426e+08 (94%)</td>
<td>1.257e+08 (83%)</td>
</tr>
<tr>
<td>Maximum delay [s]</td>
<td>15445 (100%)</td>
<td>15136 (98%)</td>
<td>10189 (66%)</td>
</tr>
<tr>
<td>Time to recover [s]</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EG</th>
<th>O-D</th>
<th>Reference simulation</th>
<th>FCFS</th>
<th>Algorithm 1</th>
<th>Algorithm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy consumption [kWh]</td>
<td>Narvik - Bergfors</td>
<td>33714 (100%)</td>
<td>33983 (101%)</td>
<td>33770 (100%)</td>
<td>33957 (101%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RU2</th>
<th>Reference simulation</th>
<th>FCFS</th>
<th>Algorithm 1</th>
<th>Algorithm 2</th>
</tr>
</thead>
<tbody>
<tr>
<td># trains 00:00:00 - 07:00:00</td>
<td>Passenger 0, Freight 15</td>
<td>Passenger 0, Freight 15</td>
<td>Passenger 0, Freight 15</td>
<td>Passenger 0, Freight 15</td>
</tr>
</tbody>
</table>
Conclusions

- The QoSQE showed that the perturbation management approaches applied in ON-TIME resulted in improvements
  - in particular to the resilience and punctuality KPIs
  - less significant, but still positive outcome for the other KPIs
- Since the built-in simulator dispatching logic is used in the benchmark simulations, no quantitative conclusions can yet be drawn about the effects of perturbation management systems in real railway networks
- General implications
  - Extension to platform independence
  - Applicable to the assessment of operational data
Further work

- Formalisation of the key measures
- Application in other situations
  - future projects
  - using real operational data
    - e.g. evaluation of traffic on the Birmingham Cross City line
Thank you

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