UK Railway Systems Reliability - Modelling the Future – a case study

Nigel Best, Bradley Hyland
Network Rail
7th March 2012
Modelling the Future - Introduction

- Why did we do the work?
- What approach do we adopt?
- What results did we find?
- How could this work influence the existing railway?
- What could we do to improve overall reliability?
“The importance of this early definition is especially marked for complex whole-system transport programmes … there is currently a lack of the right models and tools that need to be deployed to support this stage of concept development.”  
- Sir Roy McNulty
What approach did we adopt?

Real world

- Define System Requirements
- Analyse
- Plan/Pilot
- Implement
- Realise Benefit

Modelling world

- Model Existing
- Identify Future Concept
- Model Future
- Structured Analysis
- Develop Actions

Empirical Evidence

Analytical Evidence

Experimental Evidence
What approach did we adopt?

Real world

- Define System Requirements
- Analyse

Modelling world

- Model Existing
- Model Future
- Structured Analysis
- Develop Actions
- Implement
- Realise Benefit
- Define System Requirements

Caveats on modelling

- It's only a model
- Models are the only way to predict detailed system behaviour of complex systems
- Models are not reality – but they can help identify where to look
- However TRAIL is a very well calibrated model
Basis of TSLG Future Railway Study

TSLG Research Contract awarded to NR to undertake simulation analyses of a conceptual future double capacity railway to understand the relationship between reliability, capacity & cost

Involved:

– Development of a high capacity timetable concept
– Timetable development using RailSys
– Development of a railway system reliability concept
– Simulation / optimisation using TRAIL

West Coast South was used as the conceptual railway
Modelling Scope

- West Coast Mainline South
- 107 Miles (Euston to Coventry /Nuneaton)
- 447 sets of points, 717 signals
- 594 weekday services
- West Coast Route Modernisation completed December 2008
TSLG Future Railway Study - Assumptions for the timetable modelling

- Timetable built in Railsys model by the NR Capability Analysis Team for 120 second headway:
  - 20 passenger tph on fast lines
  - 10 passenger tph on slow lines
  - 2 freight tph on slow lines
- No major infrastructure changes. Some additional fast line signals.
- Slow line signals doubled to mimic additional line capacity of moving block signalling
- Operating hours 05:00 – 23:00
- Fast lines: 15 minutes turnaround, 2 min dwells
- Slow lines: 10 minute turnaround, 60s dwell major stations, 30s dwells other stations
TSLG Future Railway Study – Model Development Process

High Capacity Timetable Concept
- Train Service Spec. Existing & Double Capacity Railways
- Initial Infrastructure Assumptions
  - RailSys Model Timetables
    - TRAIL Model Developed
      - Existing Railway Model Benchmark
      - Future Railway Optimisations

System Reliability Concept
- Railway Reliability Assumptions
- Railway Operations Assumptions

Train Service Spec. Existing & Double Capacity Railways

07.03.2012
TRAIL (DNV) Systems Model

• Occupancy model uses the Monte Carlo simulation method to simulate the movement of each train through the railway

• Simulates the operation of the railway for an equivalent 50 - 100 years of operation and allowing an average annual view to emerge

• Outputs railway performance in terms of incidents, lateness, delays and PPM and aligns these back to inputs including individual asset reliability or operational event data
Modelling of Asset Downtime in TRAIL

<table>
<thead>
<tr>
<th>MTBSAF</th>
<th>Mean Time Between Service Affecting Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTR</td>
<td>Time To Repair</td>
</tr>
<tr>
<td>DIF</td>
<td>Delay Impact at Failure</td>
</tr>
<tr>
<td>DIR</td>
<td>Delay Impact at Repair</td>
</tr>
<tr>
<td>MR</td>
<td>Mobilisation Response</td>
</tr>
<tr>
<td>ART</td>
<td>Active Repair Time</td>
</tr>
</tbody>
</table>
Incident Frequency & Impact Pyramid

- **Technical & Ops Failure Events**
- **Variance in Dwell time**
- **Variation to Plan**
- **Unattributed Delay from Attributed Incidents**

- **Significant Events**

**Control / Mitigation Measures Improve**

**Frequency of Incident**

**Magnitude of Incident Impact**

**Attribution Threshold**

**Prevention Measures Improve**
Existing Railway – TRAIL Modelled Performance

Good alignment between modelled 2010/11 railway & observed
Future Railway – TRAIL Performance with Existing System Reliability

120 headway (& fire break) = significant performance reduction
Future Railway Cancellations – Existing System Reliability

<table>
<thead>
<tr>
<th>Cancellations (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All Fast Services - 2010/11 Existing Railway Modelled</td>
<td>3.3%</td>
</tr>
<tr>
<td>All Fast Services - Future 120s Headway Base Case</td>
<td>8.5%</td>
</tr>
<tr>
<td>All Fast Services - Future Fire Break Base Case (- 2 paths per hour)</td>
<td>7.8%</td>
</tr>
</tbody>
</table>

120s headways = significant fast service cancellations

The fire break timetable no longer being considered in analysis because there is not a significant performance difference to the 120s Headway Base. It is also more optimistic.
What can the Railway do to improve system availability?

- **Prevention** – Reduce the number of incidents occurring whether by simplifying layouts to design out infrastructure, or design for high reliability

- **Control** – Reducing the durations of system downtime e.g. improving rapid response mobilisation

- **Mitigation** – Making operational decisions to limit the impact of a failure on services e.g. re-routing services and reducing the service pattern
TSLG Future Railway Study -

**Top-Down**

- Run *Preventative* sensitivities on each category to identify incident reductions. Compile as Optimal Case
- Use Preventative Compiled case to run *Control* sensitivities
- Use Control Compiled case to Run *Mitigation* sensitivities to identify targets
- Form single final Top-Down compiled view

**Bottom-Up**

- Identify Incident reductions using NR expert judgement
- Run final Bottom-Up view with Control & Mitigation (from Top-Down approach)

- Do the final solutions achieve 91.5% MAA PPM?
• Cost assumed to increase linearly with MTBSAF. The cost of preventing events grows exponentially to the number removed.

• Optimal reliability targets are selected where cost and effort required to further improve performance outweigh the benefit (where the curve gradient tails off)
Future Railway - Rolling Stock Sensitivity

Percentage of Services arrived within 10 minutes (%)

- Future 120s hdwy TT - Perfect Class 390 rolling stock
- Future 120s hdwy TT - Class 390 rolling stock Sensitivity Runs

Future Base Case

Optimal point on curve

Class 390 rolling stock MAA MTIN

0 10,000 20,000 30,000 40,000 50,000 60,000 70,000

0 10,000 20,000 30,000 40,000 50,000 60,000 70,000

07.03.2012
Future Railway – Infrastructure Sensitivity

Mean Time Between Service Affecting Failure (operating hours)

Percentage of Services Arrived within 10 minutes (%)

- Future 120s Headway timetable - Perfect Infrastructure
- Future 120s Headway timetable - Infrastructure Sensitivity Runs

Optimal
Future Railway – TOC/FOC Operations Sensitivity

- Future 120s Headway timetable - Perfect TOC/FOC Ops
- Future 120s Headway timetable - TOC/FOC Ops Sensitivity Runs

Optimal
Future Railway – NR Ops, Planning & Commercial Sensitivity

Percentage of Services Arrived within 10 minutes (%)

Mean Time Between Service Affecting Failure (operating hours)

Future 120s Headway timetable - Perfect NR Ops, Planning & Commercial

Future 120s Headway timetable - NR Ops, Planning & Commercial Sensitivity Runs

Optimal
Future Railway – Weather, T&V, Excluded
Sensitivity

% of Services Arrived within 10 minutes

Mean Time Between Service Affecting Failure (operating hours)

- Future 120s Headway timetable - Perfect Weather, T&V, Excluded
- Future 120s Headway timetable - Weather, T&V, Excluded
  Sensitivity Runs

Optimal
## Future Railway – Preventative Category

### Target Performance

<table>
<thead>
<tr>
<th>Prevention Categories</th>
<th>Performance</th>
<th>Original incidents per day</th>
<th>Target incidents per day</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollingstock</td>
<td>72.52%</td>
<td>6</td>
<td>4</td>
<td>Δ + 4.59%</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>72.31%</td>
<td>4</td>
<td>1</td>
<td>Δ + 4.38%</td>
</tr>
<tr>
<td>TOC/FOC Operations</td>
<td>69.81%</td>
<td>22</td>
<td>10</td>
<td>Δ + 1.88%</td>
</tr>
<tr>
<td>NR Operations</td>
<td>68.42%</td>
<td>9</td>
<td>5</td>
<td>Δ + 0.49%</td>
</tr>
<tr>
<td>Weather, T&amp;V</td>
<td>70.03%</td>
<td>5</td>
<td>2</td>
<td>Δ + 2.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Run Case</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>120s Headway TT Base Case</td>
<td>67.93%</td>
</tr>
</tbody>
</table>

**Prevention Categories**

- **Rollingstock**: 72.52% (Δ + 4.59%)
- **Infrastructure**: 72.31% (Δ + 4.38%)
- **TOC/FOC Operations**: 69.81% (Δ + 1.88%)
- **NR Operations**: 68.42% (Δ + 0.49%)
- **Weather, T&V**: 70.03% (Δ + 2.1%)

**Total**: 82.66% (Δ + 14.73%)

**07.03.2012**
Future Railway – Top-Down Optimal Preventative Targets Applied

- Percentage of Services Arrived (%)
- Journey Lateness (Minutes) at Destination or Exit Boundary

- Early Arrivals
- Late Arrivals Within PPM
- Late Arrivals Outside PPM

- MAA On-time Equivalence
- MAA PPM Equivalence

- Fast Services - Future 120s Headway Base Case
- Fast Services - Future 120s Headway Preventative Case

- 83%
- 68%
Future Railway – Bottom-Up Category Reductions

<table>
<thead>
<tr>
<th>Category</th>
<th>Improved Railway</th>
<th>Super Improved Railway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollingstock</td>
<td>50%</td>
<td>75%</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>36%</td>
<td>84%</td>
</tr>
<tr>
<td>TOC/FOC Ops</td>
<td>20%</td>
<td>70%</td>
</tr>
<tr>
<td>NR Ops, Planning &amp; Commercial</td>
<td>42%</td>
<td>74%</td>
</tr>
<tr>
<td>Weather, T&amp;V, Excluded</td>
<td>10%</td>
<td>60%</td>
</tr>
<tr>
<td>Unexplained</td>
<td>19%</td>
<td>96%</td>
</tr>
</tbody>
</table>

- Preventative measures linked to specific rationale/ assumptions at KPI level
- Improved Railway – achievable or current initiatives for CP4/5
- Super-Improved Railway – Ambitious CP6/7 solutions compiled using NR expert judgement.
Future Railway – Bottom-Up Preventative Target Performance

- Fast Services - Future 120s Headway Base Case
- Fast Services - Future 120s Headway - Improved Railway
- Fast Services - Future 120s Headway - Super Improved Railway

Journey Lateness (Minutes) at Destination or Exit Boundary

- Early Arrivals
- Late Arrivals Within PPM
- Late Arrivals Outside PPM

- MAA On-time Equivalence
- MAA PPM Equivalence

07.03.2012
Future Railway – Performance Contribution from Incident Prevention

Top Down

Bottom Up

Performance Contribution from Prevention

Future 120s Headway Base

Percentage of Trains arrived within 10 minutes

Lateness (%)
**Future Railway – Control Sensitivity**

- With preventative measures applied performance is still not good enough to be an operable railway

- Rapid Response sensitivity conducted on the Top-Down compiled preventative case

<table>
<thead>
<tr>
<th>Run Case</th>
<th>Target</th>
<th>Performance</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preventative + Control Improvement</td>
<td>Reduce maximum response times by 33%</td>
<td>82.86%</td>
<td>Δ + 0.20%</td>
</tr>
<tr>
<td>Preventative + Control Worsenment</td>
<td>Worsen maximum response times by 33%</td>
<td>82.47%</td>
<td>Δ - 0.19%</td>
</tr>
</tbody>
</table>

Rapid Response has reduced impact due to preventative measures therefore not being considered in the subsequent analysis
Future Railway – Mitigation Measures

- Incident mitigation measures were analysed using the top down sensitivity approach on the following model elements:
  - Sub-threshold Delay
  - Boundary Lateness
  - Timetable recovery
  - Off-Peak Dwell Recovery
  - On-route cancellation threshold
  - Turnaround abandonment threshold
Future Railway – Sub-threshold Delay Sensitivity

- Speeds and positioning controlled to eliminate incremental earliness and lateness
Modelling & Reporting Lateness

- Actual data
- Modelled data

Up Services
- Lateness already acquired (input in the model)

Down Services
- Modelled lateness leaving model boundary
- Actual lateness reported on leaving model boundary

Nuneaton/Coventry
- Model managed turnarounds

London Euston
- Actual service lateness reported on arrivals
- Modelled service lateness for arrivals

Modelled Geographic Area
Future Railway – Boundary Lateness Sensitivity

- Improving the whole network
Future Railway – Timetable Recovery Sensitivity

- Rolling stock capable of travelling faster than planned time used in timetable

![Graph showing the relationship between % Reduction in Sectional Running Times (SRT) and Percentage of Services Arrived within 10 minutes (%). The graph indicates a positive correlation with an increase in SRT reduction leading to an increase in the percentage of services arriving on time. A marked section shows a 5% reduction in SRT.](image-url)
**Future Railway – Mitigation Sensitivities Summary**

Study performance target of 91.5% to 92.5% achieved

<table>
<thead>
<tr>
<th>Categories</th>
<th>Performance</th>
<th>Target [MTBSAF]</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Lateness</td>
<td>86.60%</td>
<td>24 (mins)</td>
<td>Δ + 3.94%</td>
</tr>
<tr>
<td>Subthreshold Delay</td>
<td>90.56%</td>
<td>2 (mins)</td>
<td>Δ + 7.90%</td>
</tr>
<tr>
<td>Timetable Recovery</td>
<td>88.75%</td>
<td>5%</td>
<td>Δ + 6.09%</td>
</tr>
<tr>
<td>Dwell Recovery</td>
<td>-</td>
<td>N/A</td>
<td>-</td>
</tr>
<tr>
<td>On-Route Cancellations</td>
<td>-</td>
<td>N/A</td>
<td>-</td>
</tr>
<tr>
<td>Turnaround Abandonment</td>
<td>-</td>
<td>N/A</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Run Case</th>
<th>Performance</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>120s Headway TT Base Case</td>
<td>67.93%</td>
<td></td>
</tr>
<tr>
<td>120s Headway + Preventative Model (Prevention applied)</td>
<td>82.66%</td>
<td>Δ + 14.73%</td>
</tr>
<tr>
<td>120s Headway + Preventative &amp; Control</td>
<td>N/A</td>
<td>Limited Improvement</td>
</tr>
<tr>
<td>Final Optimal Target Case</td>
<td>93.72%</td>
<td>Δ + 11.06%</td>
</tr>
</tbody>
</table>
Future Railway – Optimal Target Case
Preventative + Mitigation Sensitivities - Fast Services

Journey Lateness (Minutes) at Destination or Exit Boundary

Early Arrivals
Late Arrivals Within PPM
Late Arrivals Outside PPM
MAA On-time Equivalence
MAA PPM Equivalence

83%
83%
94%
68%
### Future Railway – Optimal Target Case

**Fast Service Cancellations**

<table>
<thead>
<tr>
<th>Case</th>
<th>Cancellations (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future 120s Headway - Base Case</td>
<td>8.5%</td>
</tr>
<tr>
<td>Future 120s Headway - Preventative Case</td>
<td>3.9%</td>
</tr>
<tr>
<td>Future 120s Headway - Prevention + Mitigation Case</td>
<td>2.5%</td>
</tr>
</tbody>
</table>
Future Railway – Performance Contributions

<table>
<thead>
<tr>
<th>Case</th>
<th>Percentage of Trains arrived within 10 minutes</th>
<th>Lateness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Down Compiled Preventive + Mitigation Case</td>
<td>93.72%</td>
<td>67.93%</td>
</tr>
<tr>
<td>Improved Railway + Mitigation Case</td>
<td>88.26%</td>
<td>67.93%</td>
</tr>
<tr>
<td>Super Improved Railway + Mitigation Case</td>
<td>93.84%</td>
<td>67.93%</td>
</tr>
</tbody>
</table>

- **Performance Contribution from Mitigation**
- **Performance Contribution from Prevention**
- **Future 120s Headway Base Case**

07.03.2012
So what about the existing railway?
## Existing Railway - Sensitivities Summary

### Performance & Target Incidents per day

<table>
<thead>
<tr>
<th>Categories</th>
<th>Performance</th>
<th>Original Incidents per day</th>
<th>Target Incidents per day</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollingstock</td>
<td>86.79%</td>
<td>11</td>
<td>4</td>
<td>Δ + 1.14%</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>87.60%</td>
<td>4</td>
<td>2</td>
<td>Δ + 1.95%</td>
</tr>
<tr>
<td>TOC/FOC Operations</td>
<td>86.40%</td>
<td>21</td>
<td>11</td>
<td>Δ + 0.75%</td>
</tr>
<tr>
<td>NR Operations</td>
<td>85.79%</td>
<td>9</td>
<td>7</td>
<td>Δ + 0.14%</td>
</tr>
<tr>
<td>Weather, T&amp;V</td>
<td>86.69%</td>
<td>5</td>
<td>2 to 3</td>
<td>Δ + 1.04%</td>
</tr>
</tbody>
</table>

### Delta

**Σ 2010/11 Existing Base Case + Preventative Model**

<table>
<thead>
<tr>
<th>Model</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010/11 Existing Base Case</td>
<td>85.65%</td>
</tr>
</tbody>
</table>

**Δ**

- Δ + 4.88%

**Σ 2010/11 Existing Base Case + Preventative & Control**

<table>
<thead>
<tr>
<th>Model</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010/11 Existing Base Case + Preventative &amp; Control</td>
<td>90.91%</td>
</tr>
</tbody>
</table>

**Δ**

- Δ + 0.38%

**Σ 2010/11 Existing Base Case + Preventative, Control & Mitigation**

<table>
<thead>
<tr>
<th>Model</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010/11 Existing Base Case + Preventative, Control &amp; Mitigation</td>
<td>93.00%</td>
</tr>
</tbody>
</table>

**Δ**

- Δ + 2.09%

---

07.03.2012
Existing Railway - Optimal Target Case
Preventative, Control & Mitigation target measures applied

Percentage of Services Arrived (%)

- Early Arrivals
- Late Arrivals Within PPM
- Late Arrivals Outside PPM

Journey Lateness (Minutes) at Destination or Exit Boundary

- 2010/11 Existing Railway modelled
- Existing Railway - Prevention Targets applied
- Existing Railway - Prevention, Control & Mitigation Targets applied
Existing Railway - Optimal Target Case
Preventative, Control & Mitigation Contributions

<table>
<thead>
<tr>
<th>Compiled Run Cases</th>
<th>Percentage of Trains arrived within 10 minutes Lateness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010/11 Existing Railway modelled</td>
<td>85.65%</td>
</tr>
<tr>
<td>Prevention Targets applied</td>
<td>90.53%</td>
</tr>
<tr>
<td>Prevention &amp; Control Targets applied</td>
<td>90.91%</td>
</tr>
<tr>
<td>Prevention, Control &amp; Mitigation Targets applied</td>
<td>93.00%</td>
</tr>
</tbody>
</table>
What could we do to improve overall reliability?
Optimised Railway Design

• Use whole railway model to identify ‘preventative’ ‘control’ and ‘mitigation’ measures offering greatest benefit.

• Introduce real time management of the rail system (including TOC Train/Crew resources)

• Simplify / optimise existing railway – Japanese/ProRail approach to S&C reduction.
Deliver focused Infrastructure Reliability Improvements

- Increase focus on Asset League Tables
- Rigorous Root Cause Analysis on Worst Performing Assets
- Progress Route FMECA on all key Routes
- Advance investigation into temperature effects on equipment reliability
Step change in quality audit and technical investigation capability

- Monitor Product Supplier Quality Assurance adoption

- Invest in Environmental Test & Investigation Facilities; for both Product Integration and Problem Investigation
Improving train timekeeping and regulation

- Use on-train monitoring to validate train running times (SRTs)

Waterloo Project Finding:
Actual average braking rate of 4.6%g against T/T assumed 8%g. Potentially two train paths per hour being lost

- Undertake analysis of impact of sub-threshold lateness (unrecorded / unattributed) on railway performance
Improve measurement metrics to better understand and reduce DPI

Journey Begins

NR Influence

Infrastructure Assets / Operational Events
- Infrastructure Downtime

T&RS Assets / Operational Events
- Rolling Stock Downtime

TOC / FOC Influence

Asset Stewardship Indexes
- Infrastructure response
- Intrinsic Timetable Flexibility

Initial Trains are Delayed
- Underlying Railway Recovery Potential
- TOC Response
- Train Crew / Stock Resources

Infrastrucure Delays
- Reactionary Trains Delayed
- Trains Arrive Late (Lateness at destination)

Cancellations

PPM

07.03.2012

Measured / Managed

Not measured / managed directly (by NR)
Questions?

1. How the customer explained it
2. How the Project Leader understood it
3. How the Analyst designed it
4. How the Programmer wrote it
5. How the Business Consultant described it
6. How the project was documented
7. What operations were installed
8. How the customer was billed
9. How it was supported
10. What the customer really needed