HOLISTIC CAPACITY OF RAIL NETWORKS - EXPOSING ASSET DEFICIENCIES IN A COMPLEX SYSTEM

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Queensland Rail

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Institut für Bahntechnik GmbH

PHOTO Approach to Roma Street - SOURCE Plateway Archives
Holistic – can be defined as:

‘Emphasising the importance of the whole and the interdependence of its parts’.
Capacity – can be defined as:

‘The practical limit of a rail network to function at defined limits of operational performance’.
All Australasian Railways are under stakeholder pressure to improve services
Improved services may be provided by revised timings and/or increased frequency.
Improved services can be provided by new lines to growth areas
Improved services can be provided by new trains with enhanced performance & customer features.
The question is:
Can the existing infrastructure support an increased service frequency?
Can the existing infrastructure support additional traffic from **new lines**?
Can the existing infrastructure support the enhanced performance of new trains?
If the answer to the question is:
If the answer to the question is: ‘No’
If the answer to the question is: ‘We do not know’
If the answer to the question is: ‘Perhaps’
Or even if the answer to the question is: ‘Yes, we believe the existing infrastructure is adequate’
How can we prove it?
If additional infrastructure is required: How do we justify it?
In this figure, an infrastructure investment conflict is illustrated. The scales balance between the public and private sectors, highlighting the tension between their interests.

PHOTO: Murarrie Curve – SOURCE: Queensland Rail Trevor Bagnall
Exactly these questions confronted those responsible for the operations and development of the South East Queensland (SEQ) Rail Network.
Current SEQ Rail Network
52.8 Million passenger trips p.a.
52.8 Million passenger trips p.a.

207 - 3 Car Sets
52.8 Million passenger trips p.a.

207 - 3 Car Sets

740 kms of track
52.8 Million passenger trips p.a.

207 - 3 Car Sets

740 kms of track

147 Stations
And the Future?
Short Term Projects

- Moreton Bay Rail Link
  - Petrie to Kippa Ring
- Increased Frequency
  - Ferny Grove Line
- Changes to Train Stabling
  - Mayne & Outlying Stations
- Line Extension
  - Richlands to Springfield

New Rolling Stock

New Signalling

DIAGRAM: SEQ 2031
INDICATIVE RAIL NETWORK
SOURCE: CONNECTING SEQ 2031
Medium Term Projects

Cross River Rail
QueenslandRail

Longer Term Projects

- Sunshine Coast Line
- North West Corridor
- Ipswich to Ripley
- Salsbury to Flagstone
- Varsity Lakes To Gold Coast Airport

DIAGRAM: SEQ 2031
INDICATIVE RAIL NETWORK
SOURCE: CONNECTING SEQ 2031
All of these projects revisit the question ‘Can the existing infrastructure cope?’
Queensland Rail decided to remove speculation from the decision making
The approach was to create a scientific basis for examination of all the scenarios from ‘do nothing’ to ‘major project expenditure’
Any examination had to be ‘holistic’ - a decision in choice of rolling stock could influence subsequent investments in signalling, traction power supply, track etc.
Queensland Rail opted for a solution based on computer modelling
Computer based modelling had the potential to provide process discipline with repeatable outputs and input transparency.
Queensland Rail decided to seek bids for suppliers of software that could be used to create a ‘holistic’ model of the SEQ rail network.
An Australian company, Plateway Pty. Limited was selected to provide the software based on established software solutions used in international applications.
In a somewhat unique approach, Queensland Rail proposed that a ‘Proof of Concept’ (POC) test be conducted.
If the software could be demonstrated to meet test criteria set by Queensland Rail, then Queensland Rail would proceed with an order for the software.
If the software did not meet the test criteria then Queensland Rail would not proceed with an order for the software
The challenge was accepted
Proof of Concept Test
Queensland Rail devised benchmarks for the Proof of Concept test (POC) based on operations on the Cleveland Line.
The Cleveland Line

- 32.3kms from branch datum at Park Road
- Double track Park Road to Manly
- Single track Manly to Cleveland
Lytton Junction Feeder Station

Lytton Junction Feeder Station (LJFS) comprises 2 x 15MVA Transformers (T5 & T6)

SOURCE: QUEENSLAND RAIL, Trevor Bagnall
For the POC test Transformer LJFS – T5 supplied the double track section from Lytton Junction to Park Road
Transformer LJFS – T6 supplied the double track section from Lytton Junction to Manly and the single track section from Manly to Cleveland.
South Coast Line section normally supplied from Lytton Junction FS was supplied from Roma Street FS during POC test

For the POC test, instrumentation was fitted at LJFS and at the electrical section extremities at Park Road and Cleveland
Train operations on the Cleveland Line were monitored using data generated by the signalling system.
Cleveland Line
Remote Train Overview Application (RTOA) Screen Shot

Source: Queensland Rail – RTOA Screen Shot
Train positions were identified to track circuit level from the input to the RTOA system

Source: Queensland Rail – RTOA Screen Shot
POC Benchmarks

Photo Source: Queensland Rail – Network Picture Archive
POC Benchmarks

1. Data Transfer
2. Single Train Runs
3. Peak Hour operations

Photo Source: Queensland Rail – Network Picture Archive
POC Benchmarks

1. Data Transfer

Demonstrate that the proposed software could exchange data electronically with the existing Queensland Rail Simulation systems.
POC Benchmarks

1. Data Transfer

The data transfer capability from the existing Queensland Rail simulation tools for Timetables and Infrastructure was demonstrated in the first days of the project.
## POC Benchmarks

### 2. Single Train Runs

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Photo Source: Queensland Rail – Network Picture Archive
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### POC Benchmarks

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**POC Benchmarks**

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*Photo Source: Queensland Rail – Network Picture Archive*
The Software solution chosen by Queensland Rail for the holistic Rail Network Simulation
RAIL NETWORK SIMULATION
OpenTrack administers **input data** in three modules: rolling stock, infrastructure and timetable.

Users enter input information into these modules.
The simulation is carried out with the user defined input data. Predefined trains move on a defined track layout to the conditions set by the timetable data and the signalling system.
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OpenTrack uses a mixed discrete/continuous simulation process. The simulation process calculates both the continuous numerical solution of the differential motion equations for the vehicles (trains) and the discrete processes of signal status and delay distributions.
A wide variety of output data is developed in the simulation process. OpenTrack allows the user to present this data in many different formats and subsets including, time-space diagrams, tables and graphical elements (pictures).
Simulation Sequence per Time Step

OPENPOWERNET
RAIL ELECTRICAL
NETWORK SIMULATION

Line Voltage, Requested Effort
Separation of Simulation Tasks

Railway Operation
- Line routing and alignment
- Track layout
- Signalling system
- Train data
- Timetable
- Connecting conditions
- Operating rules

Load Flow and Energy
- Train propulsion data
- Power grid parameter
- Substation arrangement
- Feeder lines and cables
- Catenary system
- Earthing system
- Switch status

Plug-in
Railway Operation Simulation

ATM
Advanced Train Model

PSC
Power Supply Calculation

“Co-Simulation”

Interaction

Propulsion Technology

Power Supply System
Sequence of Slices
Catenary Arrangement and Conductor Model

Slice n

Material, diameter

$\text{repr} (x; y)$

Electro-magnetic coupling effects
POC Single Train Runs
January 30th and 31st 2012

Photo Source: Plateway Archives
The single train test runs were after the last and before the first, passenger train service

Photo Source: Plateway Archives
All single train runs were carried out with SMU 260 Class rolling stock in 2 x 3 Car configurations.

The SMU 260 class was chosen because of the onboard instrumentation and data logging capability.
The schedule for the test trains were based on normal service times.

Photo Source: Plateway Archives
The Monday night tests were conducted with heavy showers throughout the night.

Photo Source: Plateway Archives
The Tuesday night tests were conducted with mainly dry track with a light shower prior to our trip on the section from Manly to Cleveland.
This is a sample of the comparison between actual measurements and the simulated performance on a single train run.
- The section graphed is from Park Road to Hemmant
- The X axis is time as hh:mm:ss
- The Y axis is speed in km/h
- The brown trace is the simulated speed from OpenTrack
- The aqua trace is the speed taken from the train data logger
• The Blue trace is the Power from the train data logger
• The Red trace is the Power requested by Open Track

• The X axis is time as hh:mm:ss
• The Y axis is power in kW – negative power is braking
• The Blue trace is the Power from the train data logger
• The Brown trace is the Mechanical Power (for Traction) delivered by OpenPowerNet

• The X axis is time as hh:mm:ss
• The Y axis is power in kW – negative power is braking
• **The Blue trace is the Power from the train data logger**
• **The Purple trace is the Electrical Power (Traction + ‘Hotel’) delivered by OpenPowerNet**

- The X axis is time as hh:mm:ss
- The Y axis is power in kW – negative power is braking
• The Blue trace is the line voltage from the train data logger
• The Orange trace is the line voltage simulated by OpenPowerNet

• The X axis is time as hh:mm:ss
• The Y axis is line voltage in 10*kV
# Single Train Run Results

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| Operate instrumented test trains from Park Road to Cleveland & return (approx. 3 return trips with the first trip for calibration purposes) | H816 – All stations PKR to CNV (wet)  
H017 – All stations CNV to MNY then express to PKR (wet)  
H818 – Express PKR to MNY then all stations to CNV (dry)  
H019 – All stations CNV to PKR (dry)                                                                                                                                 |
| Maximum variation between actual and simulated train run times to be less than 2 minutes | H816 – 23s maximum deviation  
H017 – 22s maximum variation  
H818 – 14s maximum variation  
H019 – 17s maximum variation                                                                                                                                 |
| The simulated energy for each single train run would have a variation of less than 8% of that measured at Lytton Junction Feeder Station busbars. | H816 – 3.9% variation  
H017 – Not available  
H818 – 0.1% variation  
H019 – 4.5% variation                                                                                                                                 |

Photo Source: Queensland Rail – Network Picture Archive
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Maximum variation between actual and simulated train run times to be less than 2 minutes:

- H816 – 23s maximum deviation
- H017 – 22s maximum variation
- H818 – 14s maximum variation
- H019 – 17s maximum variation

The simulated energy for each single train run would have a variation of less than 8% of that measured at Lytton Junction Feeder Station busbars.

- H816 – 3.9% variation
- H017 – Not available
- H818 – 0.1% variation
- H019 – 4.5% variation

All measured energy readings for the single train runs were taken from the train instrumentation as the instrumentation at Lytton Junction Feeder Station could not discriminate between consumed and regenerated (during braking) energy.

The Data Logger readings for Run H017 were not available due to problems associated with transferring the energy readings from the train computer.

Photo Source: Queensland Rail – Network Picture Archive
## Single Train Run Results

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Photo Source: Queensland Rail – Network Picture Archive
Simulating Peak Hour Operations

Photo Source: Queensland Rail – Network Picture Archive
With the single train test runs, all trains were formed with the same generation of rolling stock i.e. SMU260 class

Photo Source: Queensland Rail – Network Picture Archive
With peak hour operations, the train consists forming scheduled services varied on a daily basis
From an electric traction perspective, trains on the Cleveland Line could be classified in 4 discrete groups.

Photo Source: Queensland Rail – Network Picture Archive
The first group are trains with Regenerative braking formed by SMU or IMU units. These trains are shown in Blue on the Train Diagram.
The energy used to brake a train can be recovered as Electrical energy if the train is fitted with Regenerative braking.

Photo Source: Queensland Rail – Network Picture Archive
The second group are trains with Dynamic braking formed by EMU 8 motor units similar to the EMU51 shown in the slide background.

These trains are shown in Orange on the Train Diagram.

Photo Source: Queensland Rail – Network Picture Archive
The energy used to brake a train is dissipated as heat if the train is fitted with Dynamic braking.

Photo Source: Queensland Rail – Network Picture Archive
The third group are trains with Dynamic braking formed by EMU 6 motor units. These trains are shown in Green on the Train Diagram.
The fourth group are trains with Dynamic braking formed by An EMU 6 motor 3 car unit + An EMU 8 motor 3 car unit

These trains are shown in Purple on the Train Diagram

Photo Source: Queensland Rail – Network Picture Archive
<table>
<thead>
<tr>
<th></th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EMU 6M</strong></td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>EMU 8M</strong></td>
<td>15</td>
<td>17</td>
<td>11</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td><strong>EMU 6M + 8M</strong></td>
<td>6</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td><strong>EMU Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>22</td>
<td>21</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td><strong>Dynamic Brake %</strong></td>
<td>52%</td>
<td>52%</td>
<td>50%</td>
<td>69%</td>
<td>40%</td>
</tr>
<tr>
<td><strong>SMU/IMU</strong></td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td><strong>Regenerative Brake %</strong></td>
<td>48%</td>
<td>48%</td>
<td>50%</td>
<td>31%</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>42</td>
<td>42</td>
<td>42</td>
<td>42</td>
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**POC 5 Day Test Cleveland Line Morning Peak train composition**
Another variable that can influence train performance is driving style.
The timetable is the same for each day but the train consist and the allocated train crew may vary.
Variations in passenger behaviour between a wet and dry day and allowance for ‘incidents’ mean that the timetable has some capacity to absorb disturbances

Photo Source: Queensland Rail – Network Picture Archive
This also means that the train crew have some capacity to vary the train performance to match operating reality.
The network simulator can calculate the behaviour of each train based on the laws of physics. Actual operational reality and thus the simulator, must also replicate the variability of human behaviour.

Photo Source: Queensland Rail – Network Picture Archive
The simulator settings that reflect reality can only be made after a close study of actual operations.
Some of the settings can be made based on measured data such as passenger loading per station and per service.
Passenger loadings will influence the mass of the train and hence the traction power demand depending on the time of day, the catchment of each station and the journey profile.
These are some of the factors that were used in a calibration process to set the model variables.
For each of the 5 days a train diagram was produced based on the actual operations, for the morning peak.
This is the train diagram for Cleveland Line Morning Peak on Tuesday January 31st 2012
Solid Lines simulated operations, 
Dashed lines actual operations 
from RTOA system
In addition to the train operation data, the co-simulation generates data relevant to the traction power supply.
Double Track Section

Maximum Voltage at train panto

Minimum Voltage at train panto

Pantograph Voltage, QR POC, Thursday peak (AgAg424Afe000)
Line Cleveland, km 0+200 to 32+400, 06:00:00.0 - 10:00:00.0

U_Panto = f(s)
Time Period Load Curve for Transformer LJFS – T5

UP TRACK

TRANSFORMER

DOWN TRACK
Time Period Load Curve for Transformer LJFS – T6
They enable electrical engineers to study the electrical stress to which a traction supply component is subjected over time.
These curves can be produced for any conductor on the simulated network such as the contact wire or, in this case, the feeders from the supply transformer.
Time Period Load Curve for Transformer LJFS – T6

4 Hour Peak Period = 14,400 seconds
The current at each of the 14,400 seconds of the simulation is considered and the maximum current during that time (ca 750 amperes) is plotted for T6.
The arrow indicates, on the exponential scale, 3,600 seconds or one hour of operation, during the peak period. The current is shown as c.a. 270 amperes
The 270 amperes is the maximum average of the currents taken for one hour during the morning peak
The 1st hour is from second 1 to second 3,601. The 2nd hour is from second 2 to second 3,602 etc. until we reach second 14,400. For each hour the average current is calculated and the maximum of these averaged currents is plotted on the curve at 3,600 seconds.
The holistic simulation also provides other possibilities to examine network performance under ‘normal’ or ‘disturbed’ operating conditions.

Photo Source: Queensland Rail – Network Picture Archive
From the POC test, this is a 1 hour slice of the train diagram showing the line voltage levels at the train pantograph.
Train Graph with indicated Pantograph Voltage
QR POC, thursday peak (AgAg424Afe000)

SINGLE TRACK WITH PASSING LOOPS

DOUBLE TRACK

- 0 V ... 22500 V
- 22500 V ... 25000 V
- 25000 V ... 26394 V
- 26394 V ... 27500 V
- 27500 V ... 29000 V
Train Graph with indicated Pantograph Voltage
QR POC, thursday peak (AgAg424Afe000)

- CVN
- WPY
- TNS
- MNY
- WNM
- LDM
- MJE
- MGS
- CRO
- ORO
- BDE
- LOT
- WNC
- WNH
- HMM
- CNQ
- NPK
- BRD

LJFS – T6
LJFS – T5

- 0 V … 22500 V
- 22500 V … 25000 V
- 25000 V … 26394 V
- 26394 V … 27500 V
- 27500 V … 29000 V
Trains accelerating at Cleveland, Birkdale & Lota

- CVN
- WPY
- TNS
- MNY
- WNM
- LDM
- MJE
- MGS
- CRO
- ORO
- BDE
- LOT
- WNC
- WNH
- HMM
- CNQ
- NPK
- BRD
Train Graph with indicated Pantograph Voltage
QR POC, thursday peak (AgAg424Afe000)

Train 1M03 2 x 3 Car 8
Motor EMU

0 V ... 22500 V  
22500 V ... 25000 V  
25000 V ... 26394 V  
26394 V ... 27500 V  
27500 V ... 29000 V
Train Graph with indicated Pantograph Voltage
QR POC, thursday peak (AgAg424Afe000)

Train 1M03 2 x 3 Car 8 Motor EMU

Train 1816 1 x 3 Car 8 Motor + 1 x 3 Car 6 Motor EMU

- 0 V ... 22500 V
- 22500 V ... 25000 V
- 25000 V ... 26394 V
- 26334 V ... 27500 V
- 27500 V ... 29000 V
Train Graph with indicated Pantograph Voltage
QR POC, thursday peak (AgAg424Afe000)

Train 1M03 2 x 3 Car 8 Motor EMU
Train 1A15 2 x 3 Car 8 Motor SMU
Train 1816 1 x 3 Car 8 Motor + 1 x 3 Car 6 Motor EMU

Symbols:
- CVN
- WPY
- TNS
- MNY
- WNM
- LDM
- MJE
- MGS
- CRO
- ORO
- BDE
- LOT
- WNC
- WNH
- HMM
- CNQ
- NPK
- BRD

Voltage Ranges:
- 0 V ... 22500 V
- 22500 V ... 25000 V
- 25000 V ... 26394 V
- 26394 V ... 27500 V
- 27500 V ... 29000 V
Magnetic Flux Density, QR POC, thursday peak (AgAg424Afe000) Line Cleveland, km 15+550, 06:26:00.0

UP = Direction Park Road to Cleveland
DN = Direction Cleveland to Park Road
RW = Return Wire
LR = Left Rail
RR = Right Rail

UP RW
CATENARY (MW)
CONTACT (CW)
DN RW
LR RR
UP
LR RR
DN
LR RR
Magnetic Flux Density, QR POC, tuesday peak (AiAg432Afe000) Line Cleveland, km 15+550, 06:37:15.0
POC 5 Day Peak Results

Photo Source: Queensland Rail – Network Picture Archive
### Benchmark Summary

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<th>Co – simulation between OpenTrack and OpenPowerNet conducted for each of the 5 days of morning peak operations. Outputs tabled to Queensland Rail</th>
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<td>Train Graph used for comparison between actual and simulated train running for each of the 5 days.</td>
<td>Train graphs produced for each of the 5 days showing the simulated against actual operations for the morning peak. Graphs handed to Queensland Rail and compared with actual operations (RTOA)</td>
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<td>The simulated energy for each day will have a variation of less than 10% of that measured at Lytton Junction Feeder Station busbars.</td>
<td>The simulated results were handed to Queensland Rail</td>
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Photo Source: Queensland Rail – Network Picture Archive
QueenslandRail Proof of Concept
energy consumption at Lytton Junction Feeding Station
30.01.2012 - 03.02.2012 6am-10am Cleveland to Park Road

- Measurement
- Simulation 90%
& 80% single line
This is the comparative performance between measured and simulated results.
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When Queensland Rail tabled their measured results it was clear that the simulated ‘hotel’ power i.e. airconditioning, lighting etc. of the trains standing at Cleveland terminus had been overestimated.
More realistic values for the ‘hotel’ power for the standing trains were entered into the model variables and the simulation for each day rerun.
This is the revised comparative performance between measured and simulated results.
Thanks to Queensland Rail & Plateway for permission to share the POC test results with you & to the Queensland Rail, Plateway & IFB Dresden personnel that made it a success.
PHOTO: Murarrie Curve – SOURCE: Queensland Rail Trevor Bagnall