Capacity Trade-Offs Analysis Tool
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Work Package 3.1
Development Objectives

- Need to cater for continued growth in rail passenger and freight traffic
  - Affordably, Sustainably, Reliably, Efficiently etc
  - Where should investment be focused?
  - Relative effectiveness of different options/solutions

- Quick, Easy to use, High-level tool to:
  - Change current mindsets and move away from specific sub-system solutions
  - Enable a whole-systems approach that takes into account the particular characteristics of the route and their mutual inter-dependencies to identify the impacts of potential options
High level assessment of alternative options to improve capacity:

Define the analysis section / represent the capabilities of the system
  • Infrastructure
  • Rolling stock
  • Operations

For each proposed improvement ‘option’
  • Represent the effects on system capabilities

Reports on:
  • Impact on the **Capacity** of the section
    • Passenger trains
    • Freight trains
  • **Affordability** of the ‘option’
    • Relative costs/Life cycle costs
  • Changes in the **Resilience** and **Adaptability** of the section
  • Changes to **Automation** levels within the system
Changing a capability can have **direct** or **indirect impacts** on other capabilities

Can impact on delivering the “planned-for” capacity increases
Whole systems approach

Adding an extra track

- Stations
- Level Crossings
- Gradient
- Curvature
- Structures
- Platform Length
- Dwell times
- Block Occupation time
- Block Length
- Power/Energy
- Braking

Longer Trains
The Tool will reflect system interactions and the impacts of trade-offs to establish the relative benefits of different innovations/improvements.

- **Determine best way to ...**
  - Get 50,000 people an hour through Route A
  - Get 300 people off the train every 3 minutes

- **... by doing ...**
  - Capability design trade-offs
  - System design trade-offs

- **... by comparing ...**
  - High performance low capacity trains vs low performance high capacity trains
  - Acceleration/braking vs number/size of doors
The C4R Tool for capability trade-offs
Increase of capacity target
Capability Trade-Offs Analysis Tool

Define the Section

Define the Track

Define Current railway Functions

Define innovation/improvement

Define Future railway Functions.
Railway Capability

Infrastructure

Section Length (km)

Track

Start Node

End Node

Signalling

Electrification Infrastructure

Wayside Structures

Sub-functions

Sub-functions

Sub-functions

Sub-functions

Sub-functions

Sub-functions
Railway Capability

Operations (Scheduling)

- Operation hours
- Passenger 1 trains
- Passenger 2 trains
- Freight Trains

Scheduled stop?
- Shares track with Passenger 2 trains
- Shares track with freight trains
- Distance between head of train and signal
- Distance between tail of train and turnout
Capability Trade-Off Analysis Tool

- Capability Status Representation
- Calculation of Outcomes
- Outcome Measures
- Visualisation of Outcomes

Current & Future capabilities

- Capacity
- Automation
- Resilience
- Adaptability
- Affordability
Capacity
The model allows the estimation of a line’s capacity in terms of:
- trains per hour per direction
- carrying capacity (passengers / cargo)

The capacity estimation component uses an **analytical model**.

It is applicable at the **network-wide** level.

The model is suitable for use on **conventional networks with mixed traffic**.

The model requires only a **modest amount of input data** and set-up time:
- infrastructure properties
- operational parameters
- traffic characteristics
**Level of detail**

- **No simulation is required** in the C4R capacity calculation process.
- The model’s level of detail can be classified as moderate.
- There is more detail than simple theoretical throughput models which can give inaccurate (optimistic) results.

- The model does not go as far as compressing blocking time staircases (c.f. UIC 406 method) which are time-intensive, sensitive to incorrect splitting of the lines and require precise timetable information.
The model differentiates
  • signalling system
  • block size (incl. moving block)
  • station layout
  • dwell time
  • rolling stock types
  • service specifications (simplified)

The calculation uses the fact that stations (and junctions) are usually the bottlenecks on predominantly passenger carrying lines
The C4R model is heavily based on a model developed for the **Taiwan Railway Administration (TRA)** [1, 2]

- The TRA model has been validated using TRA case studies (e.g. Jhongli – Songshan)
  - to verify its capacity estimates against current conditions
  - in the selection of optimal upgrades w.r.t. cost and capacity trade-offs

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Capacity calculation framework

1. **Infrastructure properties**
   - Computing average signal headway (sec)
   - Computing critical signal headway (sec)
   - Computing lost time (sec)
   - Computing operating margin (sec)

2. **Operating parameters**

3. **Traffic characteristics**

4. **Capacity of sections (trains/hr)**

   - Computing operation headway (sec)
   - Computing average operation headway according to traffic mix (sec)
Infrastructure division

- The network is subdivided into **subsections**
  - Stations and junctions are termed **nodes**
  - Each track between the nodes is a **link**

- Every subsection contains a link and the two adjacent nodes at each of its ends
Capacity analysis is conducted for each subsection

The model considers the line and adjacent station characteristics at the same time

Capacity is estimated via a series of appropriate headway calculations

For every subsection the model determines the subsection’s critical signal headway via a number of steps:

1a. Departure headway calculation from subsection’s first station
1b. Arrival headway calculation at subsection’s second station

2. Determination of critical headway (of arrival and departure headways)
Station layout

• Station track layout has a large impact on capacity

• The exact equations used for the departure and arrival signal headway calculations depend on
  • the station layout (track layout)
  • the rolling stock characteristics (performance)
  • signalling system

• For a given subsection the equations to use are defined depending on the station layouts
  • same track
  • different tracks
  • shared tracks
Critical headway

- Select the critical signal headway of the headways at the first and second stations in the subsection

- It depends on
  - rolling stock: relative speeds, stopping patterns,
  - stations: track layout / usage

<table>
<thead>
<tr>
<th>Condition</th>
<th>Position of Critical Station</th>
<th>Critical Signal Headway</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_i = t_j )</td>
<td>B ( i ) ( j )</td>
<td>( T_s = \max(T_{sD}^A, T_{sA}^B) )</td>
</tr>
<tr>
<td></td>
<td>A ( i ) ( j )</td>
<td></td>
</tr>
<tr>
<td>( t_i &lt; t_j )</td>
<td>B ( i ) ( j )</td>
<td>( T_s = \max(T_{sD}^A, T_{sA}^B - (t_j - t_i)) )</td>
</tr>
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</tbody>
</table>
Operational headway

- The operational headway consists of a sum of:
  - critical signal headway
  - buffer time between paths
  - time lost due to rolling stock speed differences

- The operational headway (tph) on subsections is an intermediate capacity output

BUT the traffic mix needs to be considered too!
Depending on the number of train groups, with the same rolling stock and service pattern, the process is repeated for all train pair combinations.

- e.g. for train group $G = \{A, B\}$:
  - 4 combinations

- or train group $G = \{A, B, C\}$:
  - 9 combinations

- For the specified proportional mix of these train groups (e.g. 7 x group A, 4 x group B, 2 x group C), the average operational headway is calculated per subsection.
Capacity KPI outputs

- Capacity of the line
  - the minimum capacity (tph) of any of the subsections

- Carrying capacity
  - the number of passenger spaces
  - or freight carrying capacity
Affordability, Resilience, Adaptability & Automation
Affordability

Topic 1: Infrastructure Costs
Topic 2: Rolling Stock Costs
Topic 3: Barriers to Entry
Topic 4: Infrastructure Environmental Costs
Topic 5: Operation Environmental costs
Resilience

Topic 1: Performance (related to punctuality)

Topic 2: Train delays due to weather events

Topic 3: Train delays due to infrastructure failures and maintenance

Topic 4: Train delays due to rolling stock/train operational failures

Topic 5: Speed of recovery from timetable perturbation

Topic 6: Accessibility to network during disruptions
Adaptability

Topic 1 Seamless Train Movement

Topic 2: Interoperability

Topic 3: Adaptable infrastructure capability

Topic 4: Legalities when implementing change
Automation

Topic 1: Operations

Topic 2: Operations-related Communications

Topic 3: Monitoring and Maintenance

Topic 4: Automation for Passengers
Case Study

Improving East Coast Mainline (ECML) capacity

Problem
Future demand exceeding available capacity
Sub-section on the major railway link between London and Edinburgh

Traffic
• 6 High Speed Intercity Passenger Services (201 kmh)
• 2 Regional Passenger Services (120 kmh)
• 1 Freight (100 kmh)

Signalling
• 4-aspect

Tracks per direction
• 1 (Doncaster to Stoke Tunnel)
• 2 (Stoke Tunnel to Peterborough)

Structures
• > 30 Level Crossings
• > 100 bridges & 4 tunnels
Case Study – Peterborough to Doncaster

- **Scenario 1**: current conditions
- **Scenario 2**: Upgrade rolling stock
- **Scenario 3**: Sc 2 + remove freight from ECML
- **Scenario 4**: Sc 3 + upgrade to ETCS L2, optimised block sections

Target: Double Capacity
Case Study – Peterborough to Doncaster

Reporting Outcomes

- **Current vs Upgraded Rolling Stock**
- **Current vs Upgraded Rolling Stock & Removal of freight**
- **Current vs Upgraded Rolling Stock, Removal of freight & ETCS L2 (w/ Optimised Blocks)**