C4R Innovation Assessment Methodologies

**Multi-Criteria Analysis**
Impacts towards Vision for 2030/2050

**Cost-Benefit Analysis**
Socio-economic appraisal

**Investment Scenarios**
- Net Present Values (NPV)
- Internal Rate of Return (IRR)

**High Capacity**
- Affordable
- Resilient
- Adaptable
- Automated

**Cost and Benefit Categories**
CBA Tool

Tool developed for CBA computation

Example of outputs: Comparison of scenarios (NPV)

<table>
<thead>
<tr>
<th>Users</th>
<th>Operators</th>
<th>Infrastructur</th>
<th>Non Users</th>
<th>Government</th>
<th>Economic Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight</td>
<td>Freight</td>
<td>Manager</td>
<td>Rail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time</td>
<td>-122 824 385 €</td>
<td>0 €</td>
<td>0 €</td>
<td>-122 824 385 €</td>
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<tr>
<td>Reliability</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
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</tr>
<tr>
<td>Operation</td>
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<td></td>
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<tr>
<td>Direct Fees</td>
<td>-115 858 559 €</td>
<td>466 099 539 €</td>
<td>115 858 559 €</td>
<td>466 099 539 €</td>
<td>0 €</td>
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<tr>
<td>Vehicle Operating Costs</td>
<td>466 099 539 €</td>
<td>2 178 296 €</td>
<td>0 €</td>
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<td></td>
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<tr>
<td>Indirect Taxes</td>
<td>89 456 304 €</td>
<td>0 €</td>
<td>89 456 304 €</td>
<td>0 €</td>
<td></td>
</tr>
<tr>
<td>Assets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment Infrastructure</td>
<td>-765 367 260 €</td>
<td>136 828 801 €</td>
<td>-765 367 260 €</td>
<td>136 828 801 €</td>
<td></td>
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<tr>
<td>Maintenance Infrastructure</td>
<td>136 828 801 €</td>
<td>0 €</td>
<td>136 828 801 €</td>
<td>0 €</td>
<td></td>
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<tr>
<td>Environmental GHG Emissions</td>
<td>50 858 649 €</td>
<td>0 €</td>
<td>50 858 649 €</td>
<td>0 €</td>
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<tr>
<td>External Effects</td>
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<td></td>
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<tr>
<td>Economic Profitability</td>
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<td>439 557 284 €</td>
<td>-512 679 901 €</td>
<td>50 858 469 €</td>
<td>-89 456 304 €</td>
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</tbody>
</table>
CBA Tool

Inputs (for each Scenario)
- Reference Trains
- Reference Road Vehicles
- Rail Infrastructure Data
- Investment Scenario
- Demand Forecast
- Other CBA Parameters & Boundary Conditions

CBA Structure Breakdown
- Investment Costs
- Maintenance Costs
- Producer Surplus
- Consumer Surplus
- Externalities
- NPV, IRR, B/C, Probabilistic Analysis
- Stakeholder Effects Matrix
# Inputs (for each Scenario)

## Reference Trains

<table>
<thead>
<tr>
<th>Consist</th>
<th>Train 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tr>
<td>Number of Locomotives</td>
<td>1</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
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<tr>
<td>Number of Wagons</td>
<td>20</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
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<tr>
<td>Length</td>
<td>425</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>m</td>
</tr>
<tr>
<td>Tare</td>
<td>490</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>T</td>
</tr>
<tr>
<td>Maximum Load</td>
<td>1000</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>T</td>
</tr>
<tr>
<td>Load Factor</td>
<td>50%</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>Load</td>
<td>500</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>T</td>
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<tr>
<td>Gross Weight</td>
<td>990</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>T</td>
</tr>
</tbody>
</table>

## Locomotives

| Power Source | Electric | # | # | # | # | # |
| Weight | 90 | # | # | # | # | T |
| Length | 25 | # | # | # | # | m |
| Operating Cost | 5 | # | # | # | # | €/km |
| Tax | 3 | # | # | # | # | # |

## Wagons

| Tare Weight | 20 | # | # | # | # | # | T |
| Maximum Load | 50 | # | # | # | # | T |
| Length | 20 | # | # | # | # | m |
| Operating Cost | 0,15 | # | # | # | # | €/km |
| Tax | 0,03 | # | # | # | # | # |

## Operating Costs

| Operating Costs (excl. Tax) | 0,016 | # | # | # | # | €/(T·km) |
| GHG Emissions | 0,002 | # | # | # | # | kg/(T·km) |
CBA Tool

Inputs
(for each Scenario)

Reference Trains

Reference Road Vehicles

Rail Infrastructure Data

Investment Scenario

Demand Forecast

Other CBA Parameters & Boundary Conditions

Reference Vehicle

<table>
<thead>
<tr>
<th></th>
<th>Truck 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
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<tbody>
<tr>
<td>Maximum Load</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Load Factor</td>
<td>60%</td>
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<tr>
<td>Load</td>
<td>15,6</td>
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<td></td>
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<tr>
<td>Operating Costs (excl. tax)</td>
<td>0,0712</td>
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<tr>
<td>Tax</td>
<td>0,0160</td>
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<tr>
<td>GHG Emissions</td>
<td>0,0420</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
**CBA Tool**

**Inputs (for each Scenario)**
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**Boundary Conditions**
- Investment Scenario
- Reference Road Vehicles

**Other CBA Parameters & Boundary Conditions**
- Switch Density: 1/km
- Max Train Length: m
- Max Axle Load: T/axle

<table>
<thead>
<tr>
<th>Section</th>
<th>Length (km)</th>
<th>Av. Speed (km/h)</th>
<th>Time (h)</th>
<th>Av. Speed (km/h)</th>
<th>Time (h)</th>
<th>Terrain Type</th>
<th>Number of Tracks</th>
<th>Switch Density</th>
<th>Max Train Length</th>
<th>Max Axle Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger</td>
<td>131,0</td>
<td>125</td>
<td>1,05</td>
<td>80</td>
<td>1,64</td>
<td>Hilly</td>
<td>2</td>
<td>0,14</td>
<td>630</td>
<td>22,5</td>
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<tr>
<td>Freight</td>
<td>42,5402</td>
<td>0,6442</td>
<td>0,0000</td>
<td>0,6442</td>
<td>0,0007</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Maintenance Costs**
- Track Fixed: €/(year-km)
- Track Variable: €/(MGT-km)
- S & C Fixed: €/(year-switch)
- S & C Variable: €/(MGT-switch)

| Track Fixed | €/(year-km) | 15600 |
| Track Variable | €/(MGT-km) | 309 |
| S & C Fixed | €/(year-switch) | 34528 |
| S & C Variable | €/(MGT-switch) | 3612 |

**Delays**
- Punctuality (%)
- P. Delays (%)
- P. Cancellations (%)
- Delays (h)

| Punctuality (%) | Passenger | 0,0% |
| P. Delays (%) | Passenger | 0,0% |
| P. Cancellations (%) | Passenger | 0,0% |
| Delays (h) | Passenger | 0,00 |
| Freight | 0,0% |
| Freight | 0,00 |
## Investment Projects

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Included in</th>
<th>Estimated Lifespan (years)</th>
<th>NPV 2015</th>
<th>NPV 2016</th>
<th>NPV 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE36 Angelholm-Maria: Upgrade to double track in existing alignment and grade-separated crossings. Reconstruction of Maria station</td>
<td>No</td>
<td>30</td>
<td>0€</td>
<td>0€</td>
<td>0€</td>
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<tr>
<td>SE37 Flackarp - Arlov: The action involves two new tracks on the route Flackarp-Arlov which constitute about 75 percent of the route</td>
<td>No</td>
<td>30</td>
<td>0€</td>
<td>0€</td>
<td>0€</td>
</tr>
<tr>
<td>SE38 Flackarp - Lund (Högevall): Expansion from two to four tracks between Flackarp and Högevall</td>
<td>No</td>
<td>30</td>
<td>0€</td>
<td>0€</td>
<td>0€</td>
</tr>
<tr>
<td>SE39 Paga if Nordost (Regional railway network improvement):</td>
<td>No</td>
<td>30</td>
<td>0€</td>
<td>0€</td>
<td>0€</td>
</tr>
<tr>
<td>SE40 Åstorp - Teckomatorp: Expansion of sidings, introduction of modern signalling systems and new stations for passenger service</td>
<td>No</td>
<td>30</td>
<td>0€</td>
<td>0€</td>
<td>0€</td>
</tr>
</tbody>
</table>

### Investment Scenario

- Reference Trains
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### Rail Passenger Demand Elasticities
- Demand elasticity with GDP
- Demand elasticity with Price
- Price elasticity with Operating Costs
- Demand elasticity with Operating Costs

### Rail Freight Demand Elasticities
- Demand elasticity with GDP
- Demand elasticity with Price
- Price elasticity with Operating Costs
- Demand elasticity with Operating Costs
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CBA Boundaries
- Time horizon: 40 years
- Year 1: 2016

Economic Boundary Conditions
- Discount rate: 4.00%
- Shadow price conversion factor: 0.95

Energy Costs

Time Valuation
- Passengers
  - Business passengers VOT: 30 €/h
  - Business passengers: 50%
  - Leisure VOT: 10 €/h
  - Leisure passengers: 10%
  - Commuter VOT: 15 €/h
  - Commuter passengers: 40%
  - Average: 22 €/h

Freight
- Rail: 1.66 €/h
- Road: 4.05 €/h
- Diverted from Road to Rail: 1.66 €/h

Externalities
- GHG Emissions Cost - Initial Value: 0.031 €/kg
- GHG Emissions Cost - Annual Growth: 0.001 €/kg
CASE STUDY 1: SWEDISH SECTIONS OF THE SCANDINAVIAN-MEDITERRANEAN CORRIDOR
‘Baseline & TEN-T’ Scenario

Maintenance or replacement of End Of Life items and Investment already planned in TEN-T corridors (timeline and costs defined in TEN-T reports)
C4R Scenarios

• Innovative Slab Track
• Advanced Monitoring
• Innovative Switches
• Innovative Freight Concepts

Introduced in the whole corridor
Key Assumptions

• Case study focused on **freight** transportation

• Time horizon: 40 years (2016-2056); Discount Rate: 4%

• Combined **C4R Infrastructure Innovations** reduce **Infrastructure Downtime** for Maintenance by 60%
  - Also reduce Maintenance Costs (German benchmark)

• Innovative Slab Track Target Cost limited to 1000 €/m of single track

• **No Increase** in Track Access Charges
Key Assumptions

‘Baseline & TEN-T’ Scenario

Current

From 2020

C4R Scenario 1

From 2025

- Maximum length:
  - Current: 630 m
  - From 2020: 750 m
  - From 2025: 1000 m

- Technologies:
  - Automatic Couplers
  - EP Brakes

Baseline & TEN-T

C4R Scenario 1

Capacity for Rail
Key Assumptions

• 5 Market Segments:

- Wagon Load
- Train Load
- Intermodal Container
- Intermodal Trailer
- Wagon Load Feeder

Example Traffic Mix Evolution

- 630 m
- 735 m
- 998 m
Results

C4R Scenario 1

- High investment in infrastructure upgrades
- Lower rail operating costs and additional Capacity, allow traffic diversion from Road to Rail
- Comparatively small benefit from GHG reduction

- Savings in track and S&C maintenance costs
- Rail freight slower than road freight

Graph showing the following:

- Infrastructure Investment: €-727,098,897
- Infrastructure Maintenance: €129,987,361
- Producer Surplus: €439,697,284
- Consumer Surplus: €50,858,469
- Externalities: €-122,824,385
- NPV: €-229,380,168

Chart 7: C4R Scenario 1 - Capacity for Rail
Assumptions

C4R Scenario 2

- C4R infrastructure innovations implemented only in most congested sections
Results

C4R Scenario 2

Much smaller investment compared with Scenario 1

Smaller benefit from modal transfer in absolute terms, but sufficient to offset investment

IRR: 4.4%
**C4R Scenario Ranking**

- Longer/heavier trucks by 2030
- Truck operating Costs reduction
- Only innovative freight concepts and minor infrastructure invest.
- Automatic couplers/EP breaks in all wagons
- Max speed increase up to 120km/h
CASE STUDY 2: MONTPELLIER – PERPIGNAN SECTION OF THE MEDITERRANEAN CORRIDOR
C4R Scenarios

Baseline

- No investment besides maintenance or replacement of End Of Life items

C4R Investment Level 1

- Operational improvements and investments to allow trains up to 1000 m

C4R Investment Level 2

- Upgrade to slab track and new S&C
- Innovative freight concepts with trains up to 1500 m
Results

C4R Investment Level 1

- No change; fixed costs model used.
- By far most significant effect from added capacity, allowing modal transfer.

- Modest investment in infrastructure, only siding extensions.
- Rail freight slower than road freight.
Results

C4R Investment Level 2

- Reduction in maintenance costs
- Additional capacity allows further traffic to be diverted from road, offsetting investment

IRR: 23,0%

Investment in slab track and S&C

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure Investment</td>
<td>-59 731 136 €</td>
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<tr>
<td>Consumer Surplus</td>
<td>-26 297 551 €</td>
</tr>
<tr>
<td>Producer Surplus</td>
<td>175 721 463 €</td>
</tr>
<tr>
<td>Externalities</td>
<td>21 146 282 €</td>
</tr>
<tr>
<td>NPV</td>
<td>126 168 531 €</td>
</tr>
</tbody>
</table>
Gains in capacity from longer trains and reduction in unavailability allow rail to maintain its current market share in the 40 year horizon of the analysis, against a baseline of expected loss.
Conclusions

• Deep Infrastructure Innovations in existing lines may be profitable in capacity constrained sections.

• Investments in Operational concepts (longer trains, EP breaks, automatic couplers, etc.) combined with minor infrastructure improvements (sidings, improved track for higher axle loads) in most cases can have very positive effects (with no increase in access charges).

• Market share targets unattainable solely through C4R innovations.
Thank you for your kind attention

Paulo TEIXEIRA
*WP 5.4. Leader*

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