New methods of evaluating railway capacity

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Content

- Motivation
- Classification of capacity definitions
- New 4-quadrant capacity model
- Conclusion
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Motivation – Case study

- To prove the potential capacity benefit of a commercial Traffic Management System (TMS) product for two infrastructure areas.

- Two major functions of the TMS product:
  - Train re-ordering
  - Train re-routing

- Operational log files for two cases:
  - Case 1: operation without TMS
  - Case 2: operation with TMS
- **Area 1:**

- **Area 2:**
Motivation – Question 1

- Increasing capacity is a main target of railway optimisation. Experts from different backgrounds are making their own efforts to increase capacity.

- There are confusions about the definitions of capacity and the methods to increase capacity, especially when the discussion of capacity involves different experts.

- Question 1: Is it feasible to classify the definitions of capacity systematically?
Motivation – Question 2

- Currently, many existing capacity studies focus on estimating the maximum theoretical capacity in different conditions.
- The topic of evaluating the dynamic capacity influenced by different optimisation methods has not been fully discussed in the latest capacity study.
- Question 2: Is it feasible to build a quantified model to evaluate the trade-off between capacity and operational quality in different operational scenarios?
Content

- Motivation
- Classification of capacity definitions
- New 4-quadrant capacity model
- Conclusion
Proposal of classifying different capacity definitions

- Capacity is the maximum number of trains per time the infrastructure can handle under specified condition.

Diagram:

- **Theoretical Level**:
  - Theoretical capacity
  - Theoretical capacity with traffic pattern
  - Theoretical capacity with optimised conflict resolution

- **Traffic Planning Level**:
  - Optimised timetable capacity
  - Non-optimised timetable capacity

- **Traffic Operating Level**:
  - Optimised operational capacity
  - Non-optimised operational capacity
Proposal of classifying different capacity definitions

- Capacity is the maximum number of trains per time the infrastructure can handle under specified condition.

Theoretical Level

- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

Traffic Planning Level

- Optimised timetable capacity
- Non-optimised timetable capacity

Traffic Operating Level

- Non-optimised operational capacity

Estimate the maximum number of trains

Count the number of trains in timetable

Count the number of trains in operational log file
Proposal of classifying different capacity definitions

- Capacity is the maximum number of trains per time the infrastructure can handle under specified condition.
Proposal of classifying different capacity definitions

**Theoretical Level**
- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

**Traffic Planning Level**
- Optimised timetable capacity
- Non-optimised timetable capacity

**Traffic Operating Level**
- Optimised operational capacity
- Non-optimised operational capacity

- Reserve time / buffers
- Disturbance / conflicts
- Optimisation methods
Proposal of classifying different capacity definitions

Theoretical Level
- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

Traffic Planning Level
- Optimised timetable capacity
- Non-optimised timetable capacity

Traffic Operating Level
- Optimised operational capacity
- Non-optimised operational capacity

Traffic pattern
Reserve time / buffers
Disturbance / conflicts
Optimisation methods
Proposal of classifying different capacity definitions

Theoretical Level
- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

Traffic Planning Level
- Optimised timetable capacity
- Non-optimised timetable capacity

Traffic Operating Level
- Optimised operational capacity
- Non-optimised operational capacity

Traffic pattern
Reserve time / buffers
Disturbance / conflicts
Optimisation methods
Proposal of classifying different capacity definitions

Theoretical Level
- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

Traffic Planning Level
- Optimised timetable capacity
- Non-optimised timetable capacity
- Generate

Traffic Operating Level
- Optimised operational capacity
- Non-optimised operational capacity

Traffic pattern
Reserve time / buffers
Disturbance/ conflicts
Optimisation methods
Proposal of classifying different capacity definitions

Theoretical Level
- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

Traffic Planning Level
- Optimised timetable capacity
- Non-optimised timetable capacity

Traffic Operating Level
- Optimised operational capacity
- Non-optimised operational capacity

Traffic pattern
- Reserve time / buffers
- Disturbance/ conflicts
- Optimisation methods
Proposal of classifying different capacity definitions

Theoretical Level
- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

Traffic Planning Level
- Optimised timetable capacity
- Non-optimised timetable capacity

Traffic Operating Level
- Optimised operational capacity
- Non-optimised operational capacity

Factors:
- Traffic pattern
- Reserve time / buffers
- Disturbance / conflicts
- Optimisation methods

Symbols:
- \(	ext{Close to} \)
- \(\geq\)
- \(\leq\)
- \(\geq \text{ or } \leq\)
Proposal of classifying different capacity definitions

Theoretical Level
- Theoretical capacity
- Theoretical capacity with traffic pattern
- Theoretical capacity with optimised conflict resolution

Traffic Planning Level
- Optimised timetable capacity
- Non-optimised timetable capacity

Traffic Operating Level
- Optimised operational capacity
- Non-optimised operational capacity

Traffic pattern
Reserve time / buffers
Disturbance / conflicts
Optimisation methods
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UIC 4-quadrant capacity model

It is a qualitative model
- There is no standard measurement of each parameter yet

It is inappropriate to compare mixed traffic with metro via this model
- This comparison is based on an experience rather than a detailed calculation
- The infrastructure situation of mixed traffic line is very different from metro.
- A large number of trains operated in metro does not indicate that mixed traffic line can operate the same number of trains by changing into a similar homogeneous traffic pattern or by operating in a lower train speed.

Only for single line
- This model is only suitable for single line, but not for nodes (such as interlocking areas and stations).
New 4-quadrant capacity model

Each parameter of the model can be quantified with the value ranged from 0 to 1.

It can be used to evaluate the influence of different optimisation methods using in traffic planning or operation for the same infrastructure area.

It can be used for single line and interlocking area.

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Saturation of trains

Heterogeneity

Speed

Performance

Stability

Non-optimised operation

Optimised operation
Measure of saturation

- The saturation measures how close the planned or observed number of trains is to the *Theoretical capacity with optimised conflict resolution*.

\[
N_{\text{area}_i} = \sum_{j=1}^{n} N_j ,
\]

\[
\text{Saturation}_{\text{area}_i} = \frac{N_{\text{area}_i}}{\text{Theoretical capacity}_{\text{optimised conflict resolution}}},
\]

*where*

- \( N_j \) is the number of train on route \( j \)
- \( N_{\text{area}_i} \) is the total number at the whole topology area \( i \)
Theoretical capacity with optimised conflict resolution

- Step 1: Count the number of trains $N$ in the operational log file,
- Step 2: Statistics of each delay case: case$_1$, ..., case$_m$,
- Step 3: Estimate the saved time if each delay case is resolved perfectly: $t_{\text{case}_1}$, ..., $t_{\text{case}_m}$,
- Step 4: Calculate the sum of saved time $t_{\text{saving}} = \sum_{i=1}^{m} t_{\text{case}_i}$,
- Step 5: Find out the minimum train running time $t_{\text{min}}$,
- Step 6: Calculate the maximum additional number of trains $K = \frac{t_{\text{saving}}}{t_{\text{min}}}$,
- Step 7: Calculate the theoretical capacity with optimised conflict resolution: $= N + K$
Measure of speed performance

- The speed performance measure how close the average speed is to the optimal speed.

\[
\text{Speed performance}_{\text{route}_j} = 1 - \frac{|\bar{v}_{\text{route}_j} - v_{\text{route}_j \text{optimal}}|}{v_{\text{max}}},
\]

\[
\text{Speed performance}_{\text{area}_i} = \frac{\sum_j \left( \text{Speed performance}_{\text{route}_j} \cdot N_{\text{route}_j} \right)}{N_{\text{area}_i}},
\]

where

- $\bar{v}_{\text{route}_j}$ is the average train speed at route $j$
- $v_{\text{route}_j \text{optimal}}$ is optimal train speed at route $j$
- $v_{\text{max}}$ is maximum train speed
- $N_{\text{route}_j}$ is train number at route $j$
- $N_{\text{area}_i}$ is train number at the whole area $i$
Optimal train speed

- The optimal speed assumes that each train is in good physical conditions to behave perfectly and correspond to the minimum headway time.
Measure of heterogeneity

- The heterogeneity measures the flexibility of the infrastructure to handle different proportional mix or trains (different train types, different train sequence and different departure/arrival time).
- The measure is from Dr. Landex.

\[
\text{Heterogeneity}_{\text{area}_i} = 1 - \frac{\sum_{i=1}^{N-2} \left( \min \left( \frac{h^D_{t,i}}{h^D_{t,i+1}}, \frac{h^D_{t,i+1}}{h^D_{t,i}} \right) \cdot \min \left( \frac{h^A_{t,i}}{h^A_{t,i+1}}, \frac{h^A_{t,i+1}}{h^A_{t,i}} \right) \right)}{N_{\text{area}_i} - 2},
\]

where:
- \(h^D_{t,i}\) is the departure headway time between train \(i\) and train \(i+1\)
- \(h^D_{t,i+1}\) is the departure headway time between train \(i+1\) and train \(i+2\)
- \(h^A_{t,i}\) is the arrival headway time between train \(i\) and train \(i+1\)
- \(h^A_{t,i+1}\) is the arrival headway time between train \(i+1\) and train \(i+2\)
- \(N_{\text{area}_i}\) is the train number at the whole \(\text{area}_i\)
- \(N_{\text{area}_i} - 1\) is the number of headways at the whole \(\text{area}_i\)
- \(N_{\text{area}_i} - 2\) is the number of headway ratios at the whole \(\text{area}_i\)

Measure of stability

- The stability measures the ability of the traffic network to handle potential disturbances. It is determined by three factors:
  - Complexity of the infrastructure layout. The more complex of the infrastructure layout is, the more disturbances might happen, then the less stability will be.
  - Conflict frequency. The higher frequency for disturbance happens, then the less stability will be.
  - Headway time. The longer headway time of each route has, the less buffer time to handle disturbance, then the less stability will be.
Build a route conflict table and calculate the conflict rate.

<table>
<thead>
<tr>
<th>Route pair state $c_{ij}$</th>
<th>AE</th>
<th>BA</th>
<th>CD</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BA</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>CD</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BC</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

$$\eta = \frac{1}{4^2} \cdot \sum_{i,j=1}^{4} c_{ij} = \frac{1}{4^2} \cdot 10 = 0.625.$$
Measure of stability – step 2
Determine the conflict frequency or route pairs

Train Sequence
(Train sequence id, Train route)

1, AE
2, AE
3, BA
4, BA
5, AE
6, CD
7, BA
8, BC
9, BA
10, AE
11, AE
12, AE
13, BA

Train Compare
(Determine a conflict route pair or not)

1, AE
2, AE
3, BA
4, BA
5, AE
6, CD
7, BA
8, BC
9, BA
10, AE
11, AE
12, AE
13, BA

Is route pair "AE AE" a conflict? Yes!

Conflict route pair name | Count
-------------------------|-----
AE AE                    | +1  

A Source of Future
Measure of stability – step 2
Determine the conflict frequency or route pairs

Train Compare
(Determine a conflict route pair or not)

<table>
<thead>
<tr>
<th></th>
<th>1, AE</th>
<th>2, AE</th>
<th>3, BA</th>
<th>4, BA</th>
<th>5, AE</th>
<th>6, CD</th>
<th>7, BA</th>
<th>8, BC</th>
<th>9, BA</th>
<th>10, AE</th>
<th>11, AE</th>
<th>12, AE</th>
<th>13, BA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Is route pair &quot;AE CD&quot; a conflict? No!!</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Is route pair &quot;AE BA&quot; a conflict? Yes!</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conflict route pair name</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE AE</td>
<td>1</td>
</tr>
<tr>
<td>AE BA</td>
<td>1+1</td>
</tr>
<tr>
<td>BA BA</td>
<td>1</td>
</tr>
<tr>
<td>BA AE</td>
<td>1</td>
</tr>
</tbody>
</table>
Measure of stability – step 2
Determine the conflict frequency or route pairs

Train Compare
(Is that the last train?)

<table>
<thead>
<tr>
<th></th>
<th>1, AE</th>
<th>1, AE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2, AE</td>
<td>2, AE</td>
</tr>
<tr>
<td>3</td>
<td>3, BA</td>
<td>3, BA</td>
</tr>
<tr>
<td>4</td>
<td>4, BA</td>
<td>4, BA</td>
</tr>
<tr>
<td>5</td>
<td>5, AE</td>
<td>5, AE</td>
</tr>
<tr>
<td>6</td>
<td>6, CD</td>
<td>6, CD</td>
</tr>
<tr>
<td>7</td>
<td>7, BA</td>
<td>7, BA</td>
</tr>
<tr>
<td>8</td>
<td>8, BC</td>
<td>8, BC</td>
</tr>
<tr>
<td>9</td>
<td>9, BA</td>
<td>9, BA</td>
</tr>
<tr>
<td>10</td>
<td>10, AE</td>
<td>10, AE</td>
</tr>
<tr>
<td>11</td>
<td>11, AE</td>
<td>11, AE</td>
</tr>
<tr>
<td>12</td>
<td>12, AE</td>
<td>12, AE</td>
</tr>
<tr>
<td>13</td>
<td>13, BA</td>
<td>13, BA</td>
</tr>
</tbody>
</table>

Is route pair "BA AE" a conflict? Yes!

Conflict route pairs

<table>
<thead>
<tr>
<th>Conflict route pair name</th>
<th>Count</th>
<th>Frequency of conflict</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE AE</td>
<td>3</td>
<td>3/13</td>
</tr>
<tr>
<td>AE BA</td>
<td>3</td>
<td>3/13</td>
</tr>
<tr>
<td>BA BA</td>
<td>1</td>
<td>1/13</td>
</tr>
<tr>
<td>BA AE</td>
<td>2+1</td>
<td>3/13</td>
</tr>
<tr>
<td>CD BC</td>
<td>1</td>
<td>1/13</td>
</tr>
<tr>
<td>BA BC</td>
<td>1</td>
<td>1/13</td>
</tr>
<tr>
<td>BC BA</td>
<td>1</td>
<td>1/13</td>
</tr>
</tbody>
</table>

Can you find next route? No!

<table>
<thead>
<tr>
<th>Route pair frequency $f_{ij}$</th>
<th>AE</th>
<th>BA</th>
<th>CD</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>3/13</td>
<td>3/13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BA</td>
<td>3/13</td>
<td>1/13</td>
<td>0</td>
<td>1/13</td>
</tr>
<tr>
<td>CD</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1/13</td>
</tr>
<tr>
<td>BC</td>
<td>0</td>
<td>1/13</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Measure of stability – step 3
Calculate the average headway of each route pair

<table>
<thead>
<tr>
<th>Train sequence id</th>
<th>Train route</th>
<th>Departure time (minute)</th>
<th>Arrival time (minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AE</td>
<td>5’</td>
<td>7’</td>
</tr>
<tr>
<td>2</td>
<td>AE</td>
<td>7.2’</td>
<td>9.2’</td>
</tr>
<tr>
<td>3</td>
<td>BA</td>
<td>13’</td>
<td>15’</td>
</tr>
<tr>
<td>4</td>
<td>BA</td>
<td>16.2’</td>
<td>19’</td>
</tr>
<tr>
<td>5</td>
<td>AE</td>
<td>22’</td>
<td>24’</td>
</tr>
<tr>
<td>6</td>
<td>CD</td>
<td>23’</td>
<td>25’</td>
</tr>
<tr>
<td>7</td>
<td>BA</td>
<td>28’</td>
<td>31.2’</td>
</tr>
<tr>
<td>8</td>
<td>BC</td>
<td>33’</td>
<td>36’</td>
</tr>
<tr>
<td>9</td>
<td>BA</td>
<td>37.2’</td>
<td>40’</td>
</tr>
<tr>
<td>10</td>
<td>AE</td>
<td>43’</td>
<td>46’</td>
</tr>
<tr>
<td>11</td>
<td>AE</td>
<td>47’</td>
<td>49’</td>
</tr>
<tr>
<td>12</td>
<td>AE</td>
<td>50’</td>
<td>53’</td>
</tr>
<tr>
<td>13</td>
<td>BA</td>
<td>55’</td>
<td>58’</td>
</tr>
</tbody>
</table>
Measure of stability – step 3
Calculate the average headway of each route pair

\[
t_{r_{ij}}^{b} = \begin{cases} 
  t_{r_{ij}}^{D} - t_{r_{ij}}^{A}, & \text{if route } i \text{ and route } j \text{ have a conflict,} \\
  0, & \text{if route } i \text{ and route } j \text{ have no conflict,}
\end{cases}
\]

\[
H_{ij} = \frac{1}{N_{ij}} \cdot \sum_{i,j} \left( t_{r_{ij}}^{D} - t_{r_{ij}}^{A} - t_{r_{ij}}^{b} \right),
\]

<table>
<thead>
<tr>
<th>Average headway of route pairs $H_{ij}$</th>
<th>AE</th>
<th>BA</th>
<th>CD</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>$\frac{1}{3} \cdot (2' + 3' + 2') \cdot \frac{60}{60} = 140$</td>
<td>$\frac{1}{3} \cdot (2' + 2' + 3') \cdot \frac{60}{60} = 140$</td>
<td>$2' \cdot 60 = 120$</td>
<td>$0$</td>
</tr>
<tr>
<td>BA</td>
<td>$\frac{1}{3} \cdot (3.2' + 3.2' + 3') \cdot \frac{60}{60} = 188$</td>
<td>$2' \cdot 60 = 120$</td>
<td>$0$</td>
<td>$3.2' \cdot 60 = 192$</td>
</tr>
<tr>
<td>CD</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
<td>$2' \cdot 60 = 120$</td>
</tr>
<tr>
<td>BC</td>
<td>$0$</td>
<td>$3' \cdot 60 = 120$</td>
<td>$0$</td>
<td>$0$</td>
</tr>
</tbody>
</table>
The weighted headway of route pair combines three factors together,

\[ H_{ij\text{ weighted}} = c_{ij} \cdot f_{ij} \cdot H_{ij} . \]

<table>
<thead>
<tr>
<th>( H_{ij\text{ weighted}} )</th>
<th>AE</th>
<th>BA</th>
<th>CD</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE</td>
<td>1 \cdot 3/13 \cdot 140</td>
<td>1 \cdot 3/13 \cdot 140</td>
<td>0 \cdot 0 \cdot 120</td>
<td>0 \cdot 0 \cdot 0</td>
</tr>
<tr>
<td>BA</td>
<td>1 \cdot 3/13 \cdot 188</td>
<td>1 \cdot 1/13 \cdot 120</td>
<td>0 \cdot 0 \cdot 0</td>
<td>1 \cdot 1/13 \cdot 192</td>
</tr>
<tr>
<td>CD</td>
<td>0 \cdot 0 \cdot 0</td>
<td>0 \cdot 0 \cdot 0</td>
<td>1 \cdot 0 \cdot 0</td>
<td>1 \cdot 1/13 \cdot 120</td>
</tr>
<tr>
<td>BC</td>
<td>0 \cdot 0 \cdot 0</td>
<td>1 \cdot 1/13 \cdot 120</td>
<td>1 \cdot 0 \cdot 0</td>
<td>1 \cdot 0 \cdot 0</td>
</tr>
</tbody>
</table>
Measure of stability – step 4
Calculate the occupation rate

<table>
<thead>
<tr>
<th></th>
<th>AE</th>
<th>BA</th>
<th>CD</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{ij \text{ weighted}}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AE</td>
<td>$1 \cdot \frac{3}{13} \cdot 140$</td>
<td>$1 \cdot \frac{3}{13} \cdot 140$</td>
<td>$0 \cdot 0 \cdot 120$</td>
<td>$0 \cdot 0 \cdot 0$</td>
</tr>
<tr>
<td>BA</td>
<td>$1 \cdot \frac{1}{13} \cdot 188$</td>
<td>$1 \cdot \frac{1}{13} \cdot 120$</td>
<td>$0 \cdot 0 \cdot 0$</td>
<td>$1 \cdot \frac{1}{13} \cdot 192$</td>
</tr>
<tr>
<td>CD</td>
<td>$0 \cdot 0 \cdot 0$</td>
<td>$0 \cdot 0 \cdot 0$</td>
<td>$1 \cdot 0 \cdot 0$</td>
<td>$1 \cdot \frac{1}{13} \cdot 120$</td>
</tr>
<tr>
<td>BC</td>
<td>$0 \cdot 0 \cdot 0$</td>
<td>$1 \cdot \frac{1}{13} \cdot 120$</td>
<td>$1 \cdot 0 \cdot 0$</td>
<td>$1 \cdot 0 \cdot 0$</td>
</tr>
</tbody>
</table>

\[ t_{\text{occarea}_k} = N_{\text{area}_k} \cdot \sum_{ij} H_{ij \text{ weighted}} \]

\[ = 13 \cdot \sum_{ij} \left(1 \cdot \frac{3}{13} \cdot 140 \cdot 2 + 1 \cdot \frac{3}{13} \cdot 188 + 1 \cdot \frac{3}{13} \cdot 120 \cdot 3 + 1 \cdot \frac{3}{13} \cdot 192 \right) \]

\[ = 1956 \text{ (sec)} \]

\[ t_{\text{occarea}_k} [\%] = \frac{t_{\text{occarea}_k} \cdot \eta}{T} = \frac{1956 \text{ (sec)} \cdot 0.625}{3600 \text{ (sec)}} \approx 34\% , \]
The stability can be measured according to the occupation rate.

\[ \text{Stability}_{\text{area}_i} \approx 1 - t_{\text{ooc}_\text{area}_i}[^\%] = 1 - 34\% = 66\%. \]
Compare the influence of different optimisation methods on the trade-off
Comparison

\[
\begin{align*}
\text{Saturation vs. Stability}_{\text{Op2:Op1}} &= \frac{\text{Saturation}_{\text{Operation 2}} \cdot \text{Stability}_{\text{Operation 2}}}{\text{Saturation}_{\text{Operation 1}} \cdot \text{Stability}_{\text{Operation 1}}}, \\
\text{Saturation vs. Speed}_{\text{Op2:Op1}} &= \frac{\text{Saturation}_{\text{Operation 2}} \cdot \text{Speed}_{\text{Operation 2}}}{\text{Saturation}_{\text{Operation 1}} \cdot \text{Speed}_{\text{Operation 1}}}, \\
\text{Saturation vs. Heterogeneity}_{\text{Op2:Op1}} &= \frac{\text{Saturation}_{\text{Operation 2}} \cdot \text{Heterogeneity}_{\text{Operation 2}}}{\text{Saturation}_{\text{Operation 1}} \cdot \text{Heterogeneity}_{\text{Operation 1}}}, \\
\text{Saturation vs. Saturation}_{\text{Op2:Op1}} &= \frac{\text{Saturation}_{\text{Operation 2}}}{\text{Saturation}_{\text{Operation 1}}}.
\end{align*}
\]
Case study of the new 4-quadrant capacity model

- Saturation vs. Stability
Case study of the new 4-quadrant capacity model

- Saturation vs. Speed performance
Case study of the new 4-quadrant capacity model

- Saturation vs. Heterogeneity

Legend:
- Small station
- Main station
- Interlocking area XX for case study
- TMS has positive effect on heterogeneity
- TMS has no positive effect on heterogeneity
Content

- Motivation
- Classification of capacity definitions
- New 4-quadrant capacity model
- Conclusion
Achievements

- It proposed a classification of capacity definitions, which distinguishes the analysis of dynamic capacity influenced by different optimisation methods from the analysis of theoretical capacity under different restrictions.

- It proposed a new 4-quadrant capacity model, which provides a new method to evaluate the trade-off between capacity and quality in different traffic planning or operations.
Remaining question

- Using the new 4-quadrant capacity model, it proposed a method to compare two or more different operations or planning on the trade-off between capacity and quality.

- The method multiplies two quantified parameters. It is unclear whether this method is appropriate, which has to be discussed in the future study.
Thank you for your attention.