Optimizing Rail Route through Infrastructure and Rolling stock Improvements

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HSR can generally be achieved through:
- Dedicated lines
- Incremental Improvements: existing infrastructure or rolling stock can be improved in various ways to increase train speed and/or reduce travel time

Upgrading the conventional railway has become the focus of Railway Reconstruction Bureau (RRB) and Taiwan Railways Administration (TRA)
- TRA is facing highly competitive service provided by the intercity bus sector on Yilan Line
- A 16-min reduction in travel time can boost the demand by about 10%
Manual process can not guarantee optimal solutions to capacity planning problems.

Several studies used network optimization techniques to develop decision support tools for railway capacity planning process.

None of past studies in the literatures takes into account the possibility to improve services by investment in rolling stock, nor the reduced travel time is considered in the optimization process.
Optimization process identifies the most cost-effective selections

- **Network Segmentation and Alternatives Generation**: define the appropriate nodes and links of the corridor for the MIP module
- **Running Time Estimation**: estimate various running time for different train type on each link by train characteristics
- **MIP Model**: takes into account future demand and all possible options along with their costs and benefits to determine the optimal investment plan
- **Solution Algorithm**: relax capacity constraint to enhance the solution efficiency
The study corridor was divided into 10 sections:

<table>
<thead>
<tr>
<th>Section</th>
<th>Origin</th>
<th>Destination</th>
<th>Upgrading Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>s05</td>
<td>s23</td>
<td>450.00</td>
</tr>
<tr>
<td>2</td>
<td>s05</td>
<td>s15</td>
<td>250.00</td>
</tr>
<tr>
<td>3</td>
<td>s10</td>
<td>s11</td>
<td>13.54</td>
</tr>
<tr>
<td>4</td>
<td>s11</td>
<td>s12</td>
<td>11.80</td>
</tr>
<tr>
<td>5</td>
<td>s12</td>
<td>s13</td>
<td>16.96</td>
</tr>
<tr>
<td>6</td>
<td>s13</td>
<td>s14</td>
<td>16.10</td>
</tr>
<tr>
<td>7</td>
<td>s14</td>
<td>s15</td>
<td>50.00</td>
</tr>
<tr>
<td>8</td>
<td>s15</td>
<td>s20</td>
<td>70.58</td>
</tr>
<tr>
<td>9</td>
<td>s20</td>
<td>s21</td>
<td>25.01</td>
</tr>
<tr>
<td>10</td>
<td>s21</td>
<td>s22</td>
<td>19.69</td>
</tr>
</tbody>
</table>

Unit: NT$ billion

**Legend:**
- New Construction Section
- Existing Upgrade Section
- Existing Section
Adopting faster train-sets is also a popular option in reducing travel time

<table>
<thead>
<tr>
<th>Train Type</th>
<th>Commuter Train</th>
<th>Push-Pull Train</th>
<th>Roller Type Tilting Train</th>
<th>Air-Spring Tilting Train</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Unit Cost (NT$ billion)</td>
<td>4.0</td>
<td>4.8</td>
<td>4.64</td>
<td>5.44</td>
</tr>
<tr>
<td>Top Speed (km/hr)</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>140</td>
</tr>
<tr>
<td>Capacity (people)</td>
<td>1262</td>
<td>624</td>
<td>380</td>
<td>372</td>
</tr>
</tbody>
</table>

- There is a trade-off between speed and cost
- The improvements in infrastructure provide **location-specific benefits**, whereas the improvements of the rolling stock offer **location-free benefits**
## Network segmentation + running time estimation process = standard travel time

<table>
<thead>
<tr>
<th>Origin-Destination</th>
<th>Without Upgrade</th>
<th>With Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Push-Pull Train</td>
<td>Roller Type Tilting Train</td>
</tr>
<tr>
<td>s10 - s11</td>
<td>3.66</td>
<td>3.44</td>
</tr>
<tr>
<td>s11 - s12</td>
<td>1.79</td>
<td>1.53</td>
</tr>
<tr>
<td>s12 - s13</td>
<td>3.03</td>
<td>2.07</td>
</tr>
<tr>
<td>s13 - s14</td>
<td>3.32</td>
<td>1.72</td>
</tr>
<tr>
<td>s14 - s15</td>
<td>7.27</td>
<td>6.38</td>
</tr>
<tr>
<td>s15 - s16</td>
<td>3.50</td>
<td>3.00</td>
</tr>
<tr>
<td>s16 - s17</td>
<td>3.00</td>
<td>2.50</td>
</tr>
<tr>
<td>s17 - s18</td>
<td>3.50</td>
<td>3.00</td>
</tr>
<tr>
<td>s18 - s19</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>s19 - s20</td>
<td>3.00</td>
<td>2.50</td>
</tr>
<tr>
<td>s20 - s21</td>
<td>4.13</td>
<td>3.48</td>
</tr>
<tr>
<td>s21 - s22</td>
<td>2.00</td>
<td>1.71</td>
</tr>
<tr>
<td><strong>Total Travel Time</strong></td>
<td><strong>39.70</strong></td>
<td><strong>32.83</strong></td>
</tr>
</tbody>
</table>

- : Section can not be upgraded  
Unit: minutes
Network Segmentation and Alternatives Generation: define the appropriate nodes and links of the corridor for the MIP module

Running Time Estimation: estimate various running time for different train type on each link by train characteristics

MIP Model: takes into account future demand and all possible options along with their costs and benefits to determine the optimal investment plan

Solution Algorithm: relax capacity constraint to enhance the solution efficiency
MIP minimizes the capital investment, operator’s cost and pax’s cost in the life cycle

Minimize:
\[
\begin{align*}
\beta_1 \sum_{p \in P} \sum_{v \in V} C_v^p h_{pv} & + \beta_2 \sum_{s \in S} \sum_{q \in Q} G_{sq} W_{sq}^s & + \beta_3 \sum_{p \in P} \sum_{v \in V} \sum_{f \in F} \sum_{(i,j) \in A} (C_{v}^p + G_{v}^p) y_{ij}^{pvf} \\
& \text{Rolling stock investment} & \text{Infrastructure investment} & \text{Operation}
\end{align*}
\]

Decision variables:
- \( h_{pv} \in \text{Integer} \quad \forall p \in P, v \in V \quad \rightarrow \quad \text{Decisions on fleet size of rolling stock} \\
- \( w_{sq} \in \{0, 1\} \quad \forall s \in S, q \in Q \quad \rightarrow \quad \text{Decisions on selection of infrastructure upgrading} \\
- \( y_{ij}^{pvf} \in \{0, 1\} \quad \forall (i,j) \in A, p \in P, v \in V, f \in F \quad \rightarrow \quad \text{Decisions on selection of train type, stopping pattern and frequency} \\
- \( x_{ij}^{pkv} \in \text{Integer} \quad \forall (i,j) \in A, p \in P, k \in K, v \in V \quad \rightarrow \quad \text{Decisions on passenger assignment} \\
- \( (\eta^+)_i^{pkv} \in \text{Integer} \quad \forall i \in O_i \cup E_i, p \in P, v \in V, f \in F \quad \rightarrow \quad \text{Decisions on transferring assignment} \\

State variable:
- \( a^v \in \{0, 1\} \quad \forall v \in V \quad \rightarrow \quad \text{Relationship on train type} \\
- \( t_{ij}^{pvf} \in \{0, 1\} \quad \forall i \in N, p \in P, v \in V, f \in F \quad \rightarrow \quad \text{Relationship on train type, stopping pattern, frequency}
Three Groups of Constraints: Investment, Train flow, and Passenger flow

**Group 1: Investment Constraints**

\[
\sum_{p \in P} \sum_{v \in V_{ex}} C_v^p h_v^{pv} + \sum_{s \in S} \sum_{q \in Q} G_s^q w_s^{sq} \leq B
\]

\[
\sum_{q} w_s^{sq} = 1 \quad \forall s \in S
\]

\[
\sum_{v \in V_{ex}} a_v^{v} = 1
\]

\[
h_v^{pv} \geq (1 + \omega) \left( \frac{2(\sum_{(i,j) \in A} T_v^{ij} y_{ij}^{pvf} + \sum_{i \in O} T_{buf} t_i^{pvf})}{T_{per} / H_f} \right)
\]

**Group 2: Train flow Constraints**

\[
\sum_{v \in V} \sum_{f \in F} y_{ij}^{pvf} \leq w_s^{sq} \quad \forall s \in S, p \in P, q \in Q, (i, j) \in A_{enc}(s, q)
\]

\[
a_v^{v} \geq t_i^{pvf} \quad \forall p \in P, \forall v \in V_{ex}, \forall f \in F, \forall i \in O,
\]

\[
\sum_{i \in O} \sum_{p \in P} \sum_{f \in F} t_i^{pvf} \leq \Lambda
\]

\[
\sum_{j \in D_{ex}(j)} y_{ij}^{pvf} - \sum_{j \in D_{ex}(j)} y_{ji}^{pvf} = \begin{cases} t_i^{pvf} \\ - t_i^{pvf} \\ 0 \end{cases}
\]

\[
\sum_{f \in F} \sum_{p \in P} \sum_{v \in V_{ex}} H_f y_{ij}^{pvf} \leq U_{ij} \quad \forall (i, j) \in A
\]

\[
\sum_{v \in V} \sum_{f \in F} t_i^{pvf} = 1 \quad \forall p \in P
\]

**Group 3: Passenger flow Constraints**

\[
\sum_{p \in P} \sum_{v \in V_{ex}} \sum_{s \in S} \sum_{q \in Q} x_{ij}^{pqv} - \sum_{p \in P} \sum_{v \in V_{ex}} \sum_{s \in S} \sum_{q \in Q} x_{ji}^{pqv} = \begin{cases} E_k \quad \forall i \in N_{o}^{k}, \forall k \in K \\ -E_k \quad \forall i \in N_{e}^{k}, \forall k \in K \\ 0 \quad \forall i \in N_{s}^{k}, \forall k \in K \end{cases}
\]

\[
\sum_{v \in V_{ex}} \sum_{p \in P} \sum_{j \in D_{ex}(i)} x_{ij}^{pqf} - \sum_{v \in V_{ex}} \sum_{p \in P} \sum_{j \in D_{ex}(i)} x_{ji}^{pqf} = \left( \eta^{+} \right)_i^{pqv} + \left( \eta^{-} \right)_i^{pqv} \quad \forall i \in N_{s}^{p}, \forall p \in P, \forall k \in K, \forall v \in V
\]

\[
\sum_{k \in K} x_{ij}^{pqf} \leq \sum_{f} H_f U_{ij}^{pvf} \quad \forall p \in P, \forall v \in V, \forall (i, j) \in A
\]

**Tasks:**

- **Which section(s) to upgrade?**
- **What kind of rolling stock to use?**
  - How many rolling stock is required
  - Which kind of service to provide (stopping patterns and frequencies)?
- **How to assign passengers to train services?**
Group 1: Infrastructure & Rolling Stock Investment Constraints

- \[ \sum_{p \in P} \sum_{v \in V_{ex}} C_{1}^{v} h_{pv} + \sum_{s \in S} \sum_{q \in Q} G_{1}^{sq} w_{sq} \leq B \]  \[ \text{Budget constraint} \]

- \[ \sum_{q} w_{sq} = 1 \quad \forall s \in A_{s} \]  \[ \text{One section choosing at most one upgrading alternative} \]

- \[ \sum_{v \in V_{ex}} a^{v} = 1 \]  \[ \text{Choosing one type of rolling stock for all intercity service} \]

Round-trip Time

- \[ h_{pv} \geq (1 + \omega) \left[ \frac{2( \sum_{(i,j) \in A} T_{ij} y_{ij}^{pvf} + \sum_{l \in O_{i}} T_{buf} t_{l}^{pvf} )}{T_{per} \frac{H}{f}} \right] \]  \[ \text{Estimating minimal fleet size of rolling stock} \]

Headway

- \[ \forall p \in P, \forall v \in V_{ex}, \forall f \in F \]
Group 2 : Train flow Constraints

\[ \sum_{i \in O_i} \sum_{p \in P} \sum_{f \in F} \sum_{v \in V_{ex}} t_i^{pvf} \leq \Lambda \quad \text{The limit of number of stopping patterns} \]

\[ \sum_{v \in V} \sum_{f \in F} \sum_{i \in O_i} t_i^{pvf} = 1 \quad \forall p \in P \quad \text{Relationship between stopping pattern and starting station} \]

\[ \sum_{v \in V} \sum_{f \in F} y_{ij}^{pvf} \leq w^{sq} \quad \forall s \in S, \ p \in P, \ q \in Q, \ (i, j) \in A_{eng}(s,q) \quad \text{Consistency in train flow and upgrading alternative} \]

\[ a^v \geq t_i^{pvf} \quad \forall p \in P, \ \forall v \in V_{ex}, \ \forall f \in F, \ \forall i \in O_i \quad \text{Consistency in type of train and stopping patterns} \]

\[ \sum_{j \in \delta_{ex}^+(i)} y_{ij}^{pvf} - \sum_{j \in \delta_{ex}^-(i)} y_{ji}^{pvf} = \begin{cases} t_i^{pvf} & \forall i \in N^p_o, \ p \in P, \ \forall v \in V, \ \forall f \in F \\ -t_i^{pvf} & \forall i \in N^p_e, \ p \in P, \ \forall v \in V, \ \forall f \in F \\ 0 & \forall i \in N^p_s \cup N^p_t, \ p \in P, \ \forall v \in V, \ \forall f \in F \end{cases} \quad \text{Train flow conservation} \]

\[ \sum_{f \in F} \sum_{p \in P} \sum_{v \in V} H^f y_{ij}^{pvf} \leq U_{ij} \quad \forall (i, j) \in A \quad \text{Section capacity limit} \]
Group 3: Passenger flow Constraints

\[
\sum_{p \in P} \sum_{v \in V} \sum_{j \in \delta^+(i)} x_{ij}^{pkv} - \sum_{p \in P} \sum_{v \in V} \sum_{j \in \delta^-(i)} x_{ji}^{pkv} = \begin{cases} 
E^k & \forall i \in N^k_o, \forall k \in K \\
-E^k & \forall i \in N^k_e, \forall k \in K \\
0 & \forall i \in N^k_s, \forall k \in K 
\end{cases}
\]

\[
\sum_{v \in V} \sum_{j \in \delta^-(i)} x_{ij}^{pkv} - \sum_{v \in V} \sum_{j \in \delta^+(i)} x_{ji}^{pkv} = 0 \quad \forall i \in N^p, \forall p \in P, \forall k \in K
\]

\[
\sum_{j \in \delta^-(i)} x_{ij}^{pkv} - \sum_{j \in \delta^+(i)} x_{ji}^{pkv} = (\eta^+)^{pkv}_i + (\eta^-)^{pkv}_i \quad \forall i \in N^p, \forall p \in P, \forall k \in K, \forall v \in V
\]

\[
\sum_{f \in F} \sum_{p \in P} \sum_{v \in V} H^f y_{ij}^{pvf} \leq U_{ij} \quad \forall (i, j) \in A
\]

\[
\sum_{k \in K} x_{ij}^{pkv} \leq \sum_{f} H^f U_{1v} y_{ij}^{pvf} \quad \forall p \in P, \forall v \in V, \forall (i, j) \in A
\]

- **Passenger flow conservation**
- **No transferring at non-stop stations**
- **Recording transferring behavior**
- **Section capacity limit**
- **Hard constraint**
- **Train capacity limit**
Reducing the solution space by limiting the possible options in MIP model

The criteria will stop when the objective value doesn’t decrease anymore

Upgrading alternatives & stopping patterns

Constraints function

- MIP can choose what have been chosen in RMIP
- MIP can not choose what have not been chosen in RMIP
Two case studies were conducted to optimize the improvements in infrastructure and rolling stock

- **Case I : Small network**
  - To compare the efficiency between proposed MIP and solution algorithm

- **Case II : TRA network (Shulin to Hualien)**
  - To prove the fact that the best strategy is a combination of infrastructure upgrade and rolling stock acquisition

**Network Improvement Optimizer**

**Inputs**
- Upgrading Alternatives
- Types of Rolling stock
- Standard Running Time
- Upgrade and O&M Cost
- O-D Matrix

**Outputs**
- Optimal Upgrading Alternative
- Optimal Rolling stock
  - Fleet Size
  - Stopping Pattern
  - Service Frequency
Case I - Small network: Compare the solution and efficiency between MIP and algorithm

<table>
<thead>
<tr>
<th>Engineering Section</th>
<th>Property</th>
<th>Origin</th>
<th>Destination</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>New Construction</td>
<td>s04</td>
<td>s07</td>
<td>250.00</td>
</tr>
<tr>
<td>II</td>
<td>Upgrading</td>
<td>s11</td>
<td>s12</td>
<td>13.54</td>
</tr>
<tr>
<td>III</td>
<td>Upgrading</td>
<td>s12</td>
<td>s13</td>
<td>11.80</td>
</tr>
</tbody>
</table>

Unit: NT$ billion

Train Type

<table>
<thead>
<tr>
<th>Train Type</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Cost</td>
<td>24.0</td>
<td>23.2</td>
<td>27.2</td>
<td>20.0</td>
</tr>
<tr>
<td>Ac./De. Time</td>
<td>1.0/1.5</td>
<td>0.5/1.0</td>
<td>0.5/1.0</td>
<td>0.5/1.0</td>
</tr>
<tr>
<td>Capacity (people)</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

Legend:
- New Construction Section
- Existing Upgrade Section
- Existing Section

No. of Variables: 46,265
No. of Equations: 9,307
Solution Time: 233 sec
Solution algorithm reduces the solution time by 97% in case I

<table>
<thead>
<tr>
<th></th>
<th>Investment Cost</th>
<th>Maintenance Cost</th>
<th>Traveling Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infrastructure</td>
<td>Rolling stock</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>MIP</td>
<td>13.54</td>
<td>312.00</td>
<td>325.40</td>
<td></td>
</tr>
<tr>
<td>Algorithm</td>
<td>13.54</td>
<td>312.00</td>
<td>325.40</td>
<td></td>
</tr>
</tbody>
</table>

(Unit: billion NT$)

**Legend:**
- **New Construction Section**
- **Existing Upgrade Section**
- **Existing Section**

Solution Time (sec.): **233** vs. **7**

**Reduction:** 97%
Case II: Applying algorithm to TRA real network from Shulin to Hualien

**Network Information**
- In Taiwan, the corridor is responsible to transport passengers from eastern side to northern side.
- This corridor contains 46 stations
- We considered 5,019 O-D pairs

**Engineering Sections**
- **New Construction**
  - s1: Section from Nangang to Toucheng
  - s2: Section from Nangang to Shuangxi
  - s8: Section from Shuangxi to Daxi
- **Existing Upgrade**
  - s3 ~ s7, s9, s10

**Rolling Stock**
- Push-pull train
- Roller type tilting train
- Air-spring tilting train
- Commuter train
# Possible investment strategies in infrastructure and rolling stock upgrades

## Input Information

<table>
<thead>
<tr>
<th>Section</th>
<th>Origin</th>
<th>Destination</th>
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</tr>
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<td>3</td>
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<td>s11</td>
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<tr>
<td>4</td>
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<td>s13</td>
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<tr>
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<td>s20</td>
<td>s21</td>
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</tr>
<tr>
<td>10</td>
<td>s21</td>
<td>s22</td>
<td>19.69</td>
</tr>
</tbody>
</table>

### Without Upgrade

<table>
<thead>
<tr>
<th>Origin-Destination</th>
<th>Push-Pull Train</th>
<th>Roller Type Train</th>
<th>Air Spring Train</th>
<th>Commuter Train</th>
</tr>
</thead>
<tbody>
<tr>
<td>s10 - s11</td>
<td>3.66</td>
<td>3.44</td>
<td>3.36</td>
<td>3.66</td>
</tr>
<tr>
<td>s11 - s12</td>
<td>1.79</td>
<td>1.53</td>
<td>1.46</td>
<td>1.79</td>
</tr>
<tr>
<td>s12 - s13</td>
<td>3.03</td>
<td>2.07</td>
<td>2.21</td>
<td>3.03</td>
</tr>
<tr>
<td>s13 - s14</td>
<td>3.32</td>
<td>1.72</td>
<td>1.88</td>
<td>3.36</td>
</tr>
<tr>
<td>s14 - s15</td>
<td>7.27</td>
<td>6.38</td>
<td>5.94</td>
<td>7.32</td>
</tr>
<tr>
<td>s15 - s16</td>
<td>3.50</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>s16 - s17</td>
<td>3.00</td>
<td>2.50</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>s17 - s18</td>
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<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
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<td>1.50</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>s19 - s20</td>
<td>3.00</td>
<td>2.50</td>
<td>2.50</td>
<td>3.00</td>
</tr>
<tr>
<td>s20 - s21</td>
<td>4.13</td>
<td>3.48</td>
<td>3.48</td>
<td>4.19</td>
</tr>
<tr>
<td>s21 - s22</td>
<td>2.00</td>
<td>1.71</td>
<td>1.71</td>
<td>2.06</td>
</tr>
</tbody>
</table>

### With Upgrade

<table>
<thead>
<tr>
<th>Origin-Destination</th>
<th>Push-Pull Train</th>
<th>Roller Type Train</th>
<th>Air Spring Train</th>
<th>Commuter Train</th>
</tr>
</thead>
<tbody>
<tr>
<td>s10 - s11</td>
<td>1.38</td>
<td>1.38</td>
<td>1.38</td>
<td>1.64</td>
</tr>
<tr>
<td>s11 - s12</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
<td>1.36</td>
</tr>
<tr>
<td>s12 - s13</td>
<td>1.62</td>
<td>1.62</td>
<td>1.62</td>
<td>1.91</td>
</tr>
<tr>
<td>s13 - s14</td>
<td>2.31</td>
<td>2.31</td>
<td>2.31</td>
<td>2.73</td>
</tr>
<tr>
<td>s14 - s15</td>
<td>3.69</td>
<td>3.82</td>
<td>3.69</td>
<td>4.36</td>
</tr>
<tr>
<td>s15 - s16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>s16 - s17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>s17 - s18</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>s18 - s19</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>s19 - s20</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>s20 - s21</td>
<td>2.31</td>
<td>2.31</td>
<td>2.31</td>
<td>2.73</td>
</tr>
<tr>
<td>s21 - s22</td>
<td>1.62</td>
<td>1.62</td>
<td>1.62</td>
<td>1.91</td>
</tr>
</tbody>
</table>

### Total Travel Time

- 39.70
- 32.83
- 32.54
- 38.41
- 28.58
- 26.71
- 26.58
- 29.64

- Section can not be upgraded

Unit: NT$ billion

---

### Legend:
- New Construction Section
- Existing Upgrade Section
- Existing Section

---

## Section Origin Destination Upgrading Cost

1. s05 s23 450.00
2. s05 s15 250.00
3. s10 s11 13.54
4. s11 s12 11.80
5. s12 s13 16.96
6. s13 s14 16.10
7. s14 s15 50.00
8. s15 s20 70.58
9. s20 s21 25.01
10. s21 s22 19.69

### Unit Cost (NT$ billion)

- Commuter Train
- Push-Pull Train
- Roller Type Train
- Air Spring Train

### Ac./De. Time (min)

- 0.5/1.0
- 1.0/1.5
- 0.5/1.0
- 0.5/1.0

### Capacity (people)

- 1262
- 624
- 380
- 372

---

## Train Type

- Commuter Train
- Push-Pull Train
- Roller Type Train
- Air Spring Train

---

## Origin-Destination

- Nangang S05
- Cidu S10
- Nuannuan S11
- Shijiaoing S12
- Ruifang S13
- Houtong S14
- Shuangxi S15
- Gongliao S16
- Fulong S17
- Sihcheng S18
- Dali S19
- Daxi S20
- Waiao S22
- Toucheng S23
- To Taipei
- To Yilan
Apply algorithm to TRA network under the limit of seven stoppings patterns

The best strategy is a combination of infrastructure upgrade and rolling stock acquisition.
We developed an innovative method for identifying the most cost-effective strategy

- We determines the most cost-effective strategy including *infrastructure* and *rolling stock upgrades*.

- The process and optimization module can also be adapted for scenarios where only one of the two types of alternatives, upgrading infrastructure or rolling stock, is considered.

- The outcome of this research can support development of new HSR corridors and enable **better prioritization of resources** and **cost savings** in design, construction and operations.
Thank You! Wish a Great Rail Future

Railway Technology Research Center at National Taiwan University

NTU Civil Research Building, Rm 907
No.188, Sec. 3, Xinhai Rd., Da-an Dist.,
Taipei City 106, Taiwan
Telephone Number: +886-2-3366-4362
Email: yclai@ntu.edu.tw
Website: http://www2.ce.ntu.edu.tw/~railway/
HSR route studies often focus on increasing maximum speed, but this may not result in the most cost-effective improvement.

For example:

- 70 to 100 KPH or 130 to 160 KPH
- 30% Reduction of Journey Time vs. Only 18% Reduction of Journey Time

It is essential to establish a decision support process to identify the most cost-effective strategy for reducing corridor travel time.
The concept of solution algorithm is relaxing capacity constraint

\[ \sum_{k \in K} x_{ij}^{pkv} \leq \sum_{f} H_f U^v y_{ij}^{pf} \leq \sum_{f} H_f U^v y_{ij}^{pf} \]

- **Passenger flow**
- **Train flow**

- **Two meanings of the capacity constraint are presented in equation**

  1. \[ \sum_{k \in K} x_{ij}^{pkv} \leq \sum_{f} y_{ij}^{pf} \] **Consistency in train flow and passenger flow** (weak constraint)

  2. \[ \sum_{k \in K} x_{ij}^{pkv} \leq \sum_{f} H_f U^v y_{ij}^{pf} \] **Carrying capacity exceeding ridership** (strong constraint)
What will the relaxed MIP do?

\[
\sum_{k \in K} x_{ij}^{pkv} \leq \sum_{f} y_{ij}^{pvf}
\]

- **New meanings of the relaxed constraint**
  - Passengers with same origin and destination will choose the **shortest route** because the limit of **train capacity is relaxed**
  - Service frequency of stopping patterns will naturally be **one** due to minimizing the **operating cost**
  - **Upgrading alternatives & stopping patterns** in relaxed MIP will be better than original MIP
## The analysis under different stopping pattern limit

<table>
<thead>
<tr>
<th>Stopping Patterns No.</th>
<th>Variables</th>
<th>Constraints No.</th>
<th>Solution Time (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
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<tr>
<td>P2</td>
<td>441,209</td>
<td>73,177</td>
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<tr>
<td>P3</td>
<td>658,659</td>
<td>97,891</td>
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<td>874,321</td>
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<td>P7</td>
<td>1,391,844</td>
<td>1,525,688</td>
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</tbody>
</table>

(Unit: billion NT$)