Optimization of Stopping Patterns and Service Plans for Intercity Passenger Railways

C.S. James Suen, Ph.D.
Railway Transportation Research Center,
Sinotech Consultant Engineering, INC
james_suen@sinotech.org.tw

S.K. Jason Chang, Ph.D.
Department of Civil Engineering
National Taiwan University
skchang@ntu.edu.tw
Agenda

1. Introduction
2. Stopping Pattern Model
3. Train Frequency Model
4. Case Study
5. Conclusions and Further Works
Taiwan

- **Taipei**: 3,000 sq km, Pop 6.8 m
  - Car - 2.5 m, Motorcycle - 3.2 m
  - Metro 136 km + Pre-BRT 60 km
  - Airport Link: 53 Km

- **Kaohsiung**: 2,200 sq km, Pop 2.8 m
  - Car - 0.7 m, Motorcycle - 2.3 m
  - Metro 43 km + Tramway 15 km

- **Freeway Network**: 998 Km
- **Conventional Rail**: 1,065 Km
- **High Speed Rail**: the journey b/w Taipei and Kaohsiung (345km) 90 minutes.
1. Introduction

Typical planning process for intercity passenger railway systems

**Input**
- Marketing research, demand modeling, historical ticketing
- Train travel time for each stopping pattern
- Line capacity, train capacity, costs, etc.
- Headway, train running time, etc.

**Planning Activity**
- Travel demand analysis
- Train stop planning
- Train service planning
- Train scheduling
- Resource planning (rolling stocks, crew, track)

**Output**
- Origin-destination (O-D) matrix
- Combination of stopping patterns
- Service frequency and ridership for each pattern
- Timetable

**Scope of the study**

1. Introduction
Cases of stopping pattern

- The planning process reveals that train stop planning plays an important role in linking demand side and supply side.
- The commonly used stopping patterns include all-stop, skip-stop, and express services.
- The combination of possible stopping patterns is enormous but only a few are selected for operations.
Cases of service frequency

- Once the stopping patterns are specified, the service frequency of each pattern in different time periods is then planned.
- Train service planning should consider lots of factors such as capacity, operation cost, station design and other limitations.

<table>
<thead>
<tr>
<th>Time period</th>
<th>Service type1</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
<th>...</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Express</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>...</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Skip-stop</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>...</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>All stop</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>...</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Total frequency</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>...</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>
To determine how to allocate stopping patterns and train service frequencies in the best way

- Train stopping patterns and service frequencies are usually determined by experienced personnel or political pressure without scientific validations.
- Experienced railroaders may identify good solutions but *this does not guarantee that all possible combinations have been evaluated*.
- Political arguments usually favor a small portion of passengers, which *may increase passenger travel time and operation cost*.
- The study develops models to obtain the optimal combination of stopping patterns and service frequencies.
2. Stopping Pattern Model

The problem scale for train stopping patterns

- A greater number of stations \( n \) or expected patterns \( r \) results in a larger solution space

There are \( (n-2) \) stations where train can stop or pass through

- Stations: \( n \)
  - Intermediate stations: \( n-2 \)

- Types of stopping patterns provided by operator: \( r \)

- Number of stopping patterns: \( 2^{n-2} \)

- Combination of possible stopping patterns:
  \[
  C_r = \frac{2^{n-2}}{r! \times (2^{n-2} - r)!}
  \]

An optimization model for obtaining combination of stopping patterns is needed
Train stopping pattern model is formulated as a mixed integer programming problem (MIPP)

**Objective:**

Minimize Total Passenger In-vehicle Time

**Subject to:**

*Travel Time Constraint*

*Passenger Service Constraint* (passenger select a pattern on the basis of shortest path and time saving)

*No. of stopping patterns Constraint* (provided by operator)
Genetic Algorithm is proposed to efficiently solve the MIPP

- **MIPP Model:**
  - The study integrates C++/MFC technique with CPLEX solver, which is feasible for small-scale problems
- **GA is developed for large-scale problems**
Performance of GA for solving MIPP

Average generations to converge in GA Model vs Efficiency of GA

GA Model is more capable to tackle large-scale problems
A process of Genetic Algorithm and its characteristics

- “Express and all-stop services” are produced in the initial population to speed up convergence
- “Crossover module” exploits information from parents by swapping their gene segments
- “Mutation module” explores the search space by arbitrarily changing some genes in the chromosome
- “Ordinal selection” and “Elitism model” are employed to find the best combinations of stopping patterns & total passenger in-vehicle time
3. Train Frequency Model

Characteristics- Time space adjustment

- Train departing from its origin station would not be able to serve the passengers during the same hour at far downstream stations.

- The static demand is converted into dynamic demand by taking the time-space characteristics.
Characteristics - Unserved passenger transferring

- Since not all passengers can be served in the peak hour, some of them may take the trains in the next hour.
- Transfer of unserved passengers in next time period is considered in the train service planning model.
Train frequency model is formulated as a mixed integer programming problem (MIPP)

Objective:

\[ \text{Maximize} \quad \text{Operator profit} - w \times \text{Passenger total travel cost} \]

Subject to:

- \textit{Line Capacity & Train Capacity Constraint}
- \textit{Train Frequency Constraint} (minimum per hour)
- \textit{Conservation of Passenger Flow Constraint}
- \textit{Minimum and Maximum Passenger Flow Constraint}
- \textit{Transfer Ratio Constraint} (provided by operator)

\textit{Dual Model:}

\[ \text{Maximize} \quad TR - TC - w \times PTC \quad \sim \quad \text{Minimize} \quad TC + w \times PTC \]
The solution procedure

- MIPP Model:
  - The study to pre-process the parameters and O/D matrices with CPLEX to optimize the problem
  - It will output the optimal service frequencies and the ridership allocations for different patterns
4. Case Study

Taiwan High Speed Rail

- **Taiwan High Speed Rail**
  - 345 km in length (+15 km)
  - Connects major cities in western corridor: *Taipei, Taichung, and Kaohsiung*
  - Average daily ridership is around 150,000 passengers
  - **Initial stopping patterns (in 2008)**

<table>
<thead>
<tr>
<th>Taipei</th>
<th>Banciao</th>
<th>Taoyuan</th>
<th>Hsinchu</th>
<th>Taichung</th>
<th>Chiayi</th>
<th>Tainan</th>
<th>Zuoying</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Initial station in 2008</strong> (scope in this study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation in 2015/2016</td>
</tr>
<tr>
<td>Planning</td>
</tr>
</tbody>
</table>
The possible combination of stopping patterns for Taiwan High Speed Rail

<table>
<thead>
<tr>
<th>Items</th>
<th>Stage</th>
<th>2007~2015</th>
<th>2016~ until now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stations</td>
<td></td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Intermediate stations</td>
<td></td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Number of stopping patterns</td>
<td></td>
<td>$2^6 = 64$</td>
<td>$2^{10} = 1,024$</td>
</tr>
<tr>
<td>Types of patterns offered by Taiwan HSR</td>
<td></td>
<td>Totally has 4 types Mostly adopts 2 types</td>
<td>Taiwan HSR also provide 4 patterns (+ 2 more)</td>
</tr>
<tr>
<td>Combination of possible stopping patterns</td>
<td></td>
<td>$\binom{64}{4} = 635,376$</td>
<td>$\binom{1024}{4} = 45,545,029,376$</td>
</tr>
</tbody>
</table>

The study can help of tackling this problem
The optimal combinations of stopping patterns for Taiwan HSR

- Follows the actual limitations of THSRC and *takes Taipei and Zouying as the normal terminus*
- We adopt 2008’s real O-D and proceed with several scenarios

**Taiwan HSR mostly adopts pattern B & D**

- **Optimal- 2 stopping patterns**

- **Optimal- 3 stopping patterns**
The optimal combinations of stopping patterns for Taiwan HSR

**Optimal- 4 stopping patterns**

- **4A**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

- **4B**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

- **4C**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

- **4D**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

**Optimal- 5 stopping patterns**

- **5A**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

- **5B**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

- **5C**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

- **5D**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying

- **5E**:
  - Taipei
  - Banciao
  - Taoyuan
  - Hsinchu
  - Taichung
  - Chiayi
  - Tainan
  - Zuoying
The optimal combinations of stopping patterns for Taiwan HSR

**Optimal- 6 stopping patterns**

<table>
<thead>
<tr>
<th>Taipei</th>
<th>Banciao</th>
<th>Taoyuan</th>
<th>Hsinchu</th>
<th>Taichung</th>
<th>Chiayi</th>
<th>Tainan</th>
<th>Zuoying</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Optimal- 7 stopping patterns**

<table>
<thead>
<tr>
<th>Taipei</th>
<th>Banciao</th>
<th>Taoyuan</th>
<th>Hsinchu</th>
<th>Taichung</th>
<th>Chiayi</th>
<th>Tainan</th>
<th>Zuoying</th>
</tr>
</thead>
<tbody>
<tr>
<td>7A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Optimal Service Frequency for 4 stopping combinations

### B, C, D, E (optimal arrangement for 70 trains per direction under BOT requirement)

**downward**

<table>
<thead>
<tr>
<th>Time period Service pattern</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>∑</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**upward**

<table>
<thead>
<tr>
<th>Time period Service pattern</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>∑</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>70</td>
</tr>
</tbody>
</table>

### B, C, D, E (optimal frequency: 62 trains per direction)

**downward**

<table>
<thead>
<tr>
<th>Time period Service pattern</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>∑</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>62</td>
<td></td>
</tr>
</tbody>
</table>

**upward**

<table>
<thead>
<tr>
<th>Time period Service pattern</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>∑</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>total</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>62</td>
</tr>
</tbody>
</table>
Benefits of Stopping Patterns Optimized

Objective value (min)

Number of stopping patterns provided by THSRC (8 stations in 2008)

Original B, C, D, E patterns
Original B, D and two new patterns
Original B, D patterns
Optimal combination of stopping patterns

THSRC practice
6,505,301

Improve 6.2%

6,622,263

6,101,251

6,296,123

6,146,090

5,863,226

5,801,726

6,296,123

6,622,263

6,599,193

6,622,263
Benefits of Train Service Frequency Optimized

Number of stopping patterns provided by THSRC (8 stations in 2008)

Objective value (NT$)

37,325,374
37,455,136
39,271,247
39,648,284
39,756,919
39,804,496
39,861,183
40,032,750

2/3 from operation cost
1/3 from passenger travel time

THSRC practice

Optimal frequency
B, D and two new patterns (optimal frequency by model)
B, D (optimal frequency by model)
B, C, D, E (optimal frequency by model)
B, C, D, E (optimal 70 trains per direction)
B, C, D, E (original 70 trains per direction)

35,311,183
Improving 12.6%
5. Conclusions and Further Works

- The Mixed Integer Programming Models developed are useful tools for obtaining the optimal stopping patterns and the optimal service frequency.

- More alternatives of stopping patterns and their service frequencies may also be generated and evaluated by the models.

- Numerical case studies have identified the benefits of the optimization models: (1) 6.2% Improvement for passenger travel time with the optimized stopping patterns; (2) 12.6% Cost Reductions for operation and passenger travel with the optimized service frequency.

- The model considers the characteristics of railway practice, which are time space adjustment for travel demand and transfer behaviors of unserved passengers.

- Further Studies: (1) Dual Model with Objective of Minimum Operation Cost+ Passenger Cost; (2) Globally Optimal Stopping Patterns and Service Frequency; (3) Integration of High Speed Rail and Feeder Rail Services.
Thank you!

skchan@ntu.edu.tw
www.aptrc.tw
sites.google.com/site/rtrcntu/

Railway Technology Research Center
National Taiwan University