A Rail Capacity Model for Estimating Hourly Throughputs with Mixed Traffic and Complex Track Layouts

Jyh-Cherng Jong, Ph.D. PE

Civil & Hydraulic Engineering Research Center
Sinotech Engineering Consultants, Inc.
Taipei, Taiwan (R.O.C.)
Increasing Investments in Rail Systems all over the world
- better transportation and energy efficiencies
- Less gas emission

Examples in Taiwan Regional Railway (TRA)
- Elimination of grade crossings
- Building more commuter stations
- Purchasing new commuter trains
1 INTRODUCTION

The Needs of Capacity Analysis

- Cost - benefit analysis for different alternatives
- Evaluating hourly capacity in peaks
  - **Line capacity** – number of trains could be operated per hour
  - **Design capacity** – number of passenger spaces could be offered per hour
  - **Achievable capacity** – number of passengers could be transported per hour
The Difficulties in Evaluating Hourly Capacity for TRA

- Mixed traffic of intercity and commuter services
- Different train classes have different stopping patterns and operating speeds
- Even in the same class, stopping patterns, service termini and seat arrangements for different trains are not identical
- A variety of station layouts
## Models for Capacity Analysis

<table>
<thead>
<tr>
<th></th>
<th>Analytical Model</th>
<th>Optimization Model</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Data</td>
<td>Few</td>
<td>Moderate</td>
<td>Many</td>
</tr>
<tr>
<td>Precision</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Application</td>
<td>Strategy Analysis</td>
<td>Timetable Design</td>
<td>Timetable Validation</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Easiness</td>
<td>Easy to Use</td>
<td>Relatively Difficult</td>
<td>Relatively Difficult</td>
</tr>
<tr>
<td>Dependence on System</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
</tbody>
</table>
Headway is the key component for calculating capacity

- **Analytical models** did not explain how to calculate headways

- **Optimization models** usually take headways as input data

- **Simulation models** could calculating headway precisely based on blocking time diagram, but it is usually produced by commercial software
2 LITERATURE REVIEW

- **Models for Mixed Traffic and Complex Station Layouts**
  - Typically for conventional railways, where capacity is usually measured in train throughputs and inappropriate for this study

- **Models for Calculating Hourly Passenger Throughputs**
  - Typically for urban transit systems, where all trains have the same performance and stopping patterns with simple track layout
3 BASIC CONCEPT

- **Capacity Definition**
  - Maximum number of objects that can be transported on a line past a fixed point during a period of time under a given set of conditions
    - Operating conditions
    - Object to be transported
    - Spatial reference point
    - Time span
Basic Elements for Defining Capacity

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Conditions</td>
<td>Railway Condition, Traffic Condition, Control Condition</td>
</tr>
<tr>
<td>Object Unit</td>
<td>Trains, Passengers, Passenger Spaces, tons</td>
</tr>
<tr>
<td>Time Span</td>
<td>Day, Hour</td>
</tr>
<tr>
<td>Spatial Ref. Point</td>
<td>Way, Station, Section, Turn Back, Junction, Line</td>
</tr>
</tbody>
</table>

BASIC CONCEPT

3

RailZurich2009
Basic Unit for Capacity Analysis

- Dividing entire rail line into sections for each direction, while considering the station track layouts at both ends.
- Stations that are selected to divide rail line should allow overtaking and meeting operations.
4 MODEL FORMULATION

**Framework of Capacity Analysis**

\[
\text{Critical Signal Headway (s)} + \text{Lost Time (s)} + \text{Operating Margins (s)} = \text{Operating Headway (s)}
\]

\[
\text{3600 (s)} / \text{Average Headway (s)} = \text{Weighted Average by Traffic Composition (s)}
\]

\[
\text{Achievable Capacity (sps/h)} = \text{Sec. Capacity (TU/h)} \times \text{Train Capacity (sps/TU)} \times \text{Loading Diversity Factor}
\]

\[
\text{Veh. Capacity (TU/veh)} \times \text{No. of veh. in a train} \times \text{Proportion of each train type}
\]
Critical Signal Headway

Signal Headway

- Depending on operating conditions (i.e., railway, traffic, and control conditions)
- Important factors are taken into account
- Types of signal headways at stations
  - Departure headway from the same track
  - Departure headway from different track
  - Arrival headway at the same track
  - Arrival headway at different track
## Critical Signal Headway (cont.)

### Effects of Station Track Layouts

<table>
<thead>
<tr>
<th>Type</th>
<th>Example of Track Layout</th>
<th>Signal Headway</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Departure</td>
</tr>
<tr>
<td>I</td>
<td><img src="image1" alt="Platform arrangement" /></td>
<td>$T_{s,D} = T_{s,D2}$</td>
</tr>
<tr>
<td>II</td>
<td><img src="image2" alt="Platform arrangement" /></td>
<td>$T_{s,D} = \frac{1}{3}T_{s,D1} + \frac{2}{3}T_{s,D2}$</td>
</tr>
<tr>
<td>III</td>
<td><img src="image3" alt="Platform arrangement" /></td>
<td>$T_{s,D} = \frac{3}{4}T_{s,D1} + \frac{1}{4}T_{s,D2}$</td>
</tr>
<tr>
<td>IV</td>
<td><img src="image4" alt="Platform arrangement" /></td>
<td>$T_{s,D} = T_{s,D1}$</td>
</tr>
</tbody>
</table>
## Critical Signal Headway (cont.)

### Effects of Speed Variations

<table>
<thead>
<tr>
<th>Condition</th>
<th>Critical Block Section</th>
<th>Critical Signal Headway</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_i = t_j )</td>
<td>( \begin{array}{c} \text{B} \ \text{A} \end{array} ) ( i \parallel j )</td>
<td>( T_s = \max(T_{s,D}, T_{s,A}) )</td>
</tr>
<tr>
<td>( t_i &lt; t_j )</td>
<td>( \begin{array}{c} \text{B} \ \text{A} \end{array} ) ( i \parallel j )</td>
<td>( T_s = \max(T_{s,D}, T_{s,A} - (t_j - t_i)) )</td>
</tr>
<tr>
<td>( t_i &gt; t_j )</td>
<td>( \begin{array}{c} \text{B} \ \text{A} \end{array} ) ( i \parallel j )</td>
<td>( T_s = \max(T_{s,D} - (t_i - t_j), T_{s,A}) )</td>
</tr>
</tbody>
</table>
4 MODEL FORMULATION

- Lost Time
  - Additional waiting time that cannot be fully utilized for mixed traffic
4 MODEL FORMULATION

- Operating Margins
  - Used to accommodate the random effects in train operations
  - Depend on the operation efficiency of the railway system
  - Should be proportional to critical signal headway and lost time
Average Headway
- Weighted average headway by traffic composition

Hourly Train Throughput
- $3600 / \text{average headway in seconds}$

Train Capacity
- Depending on train formation, seat arrangement, etc.
4 MODEL FORMULATION

- **Design Capacity**
  - Capacity from supply point of view
  - Train throughput $\times$ average train capacity

- **Achievable Capacity**
  - Demand is not uniformly distributed over time and space
  - Loading diversity factor (peak hour factor) is introduced
  - Design capacity $\times$ loading diversity factor
5 CASE STUDY

Input Data

Railway Conditions

Jhongli (Type III) → Taoyuan (Type IV) → Shanjia (Type IV) → Shulin (Type I) → Banchiao (Type I) → Wanhua (Type II) → Taipei (Type I) → Songshan (Type I)
5 CASE STUDY

- **Input Data (Continued)**
  - **Traffic Conditions**
    - Tze-Chiang Express – 2 locomotives and 12 cars
    - Chu-Kuang Express – 1 locomotive and 8 cars
    - Commuter Train – 8 car EMU
  - **Control Conditions**
    - 3-aspect signal system
5 CASE STUDY

The Results

Average Headway (Taoyuan to Neili)

<table>
<thead>
<tr>
<th>Preceding train</th>
<th>Following train</th>
<th>$T_s$ (s)</th>
<th>$t_l$ (s)</th>
<th>$t_m$ (s)</th>
<th>$h_{ij}$ (s.)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>T.C Express</td>
<td>T.C Express</td>
<td>265.9</td>
<td>0</td>
<td>93.1</td>
<td>359.0</td>
<td>0.012</td>
</tr>
<tr>
<td>T.C Express</td>
<td>C.K Express</td>
<td>295.6</td>
<td>30.0</td>
<td>114.0</td>
<td>439.6</td>
<td>0.025</td>
</tr>
<tr>
<td>T.C Express</td>
<td>Commuter</td>
<td>239.7</td>
<td>7.5</td>
<td>86.5</td>
<td>333.7</td>
<td>0.074</td>
</tr>
<tr>
<td>C.K Express</td>
<td>T.C Express</td>
<td>229.1</td>
<td>30.0</td>
<td>90.7</td>
<td>349.8</td>
<td>0.025</td>
</tr>
<tr>
<td>C.K Express</td>
<td>C.K Express</td>
<td>318.8</td>
<td>0</td>
<td>111.6</td>
<td>430.4</td>
<td>0.049</td>
</tr>
<tr>
<td>C.K Express</td>
<td>Commuter</td>
<td>217.9</td>
<td>22.5</td>
<td>84.1</td>
<td>324.5</td>
<td>0.148</td>
</tr>
<tr>
<td>Commuter</td>
<td>T.C Express</td>
<td>237.4</td>
<td>7.5</td>
<td>85.7</td>
<td>330.6</td>
<td>0.074</td>
</tr>
<tr>
<td>Commuter</td>
<td>C.K Express</td>
<td>282.2</td>
<td>22.5</td>
<td>106.6</td>
<td>411.3</td>
<td>0.148</td>
</tr>
<tr>
<td>Commuter</td>
<td>Commuter</td>
<td>226.2</td>
<td>0</td>
<td>79.2</td>
<td>305.4</td>
<td>0.444</td>
</tr>
</tbody>
</table>

$\bar{h} = 338.8$ seconds, \[ C_o = \frac{3600}{338.8} = 10.62 \text{ TU/h} \]
# CASE STUDY

## The Results (Continued)

### Train Throughput

![Graph showing train throughputs](image)

- **Section Capacity (TU/h)**
  - SongShan
  - Taipei
  - Wanhua
  - Banciao
  - Shulin
  - Shanjia
  - Xigge
  - Taoyuan
  - Neihu

- **Throughput Values**
  - Southbound:
    - SongShan: 13
    - Taipei: 14
    - Wanhua: 13
    - Banciao: 13
    - Shulin: 8
    - Shanjia: 9
    - Xigge: 9
    - Taoyuan: 9
    - Neihu: 9
  - Northbound:
    - SongShan: 10
    - Taipei: 11
    - Wanhua: 10
    - Banciao: 10
    - Shulin: 9
    - Shanjia: 9
    - Xigge: 8
    - Taoyuan: 8
    - Neihu: 8

- **Throughput Values (Continued)**
  - SongShan: 3.58
  - Taipei: 3.62
  - Wanhua: 0.93
  - Banciao: 3.62
  - Shulin: 3.67
  - Shanjia: 5.19
  - Xigge: 1.69
  - Taoyuan: 2.77
  - Neihu: 3.09
5 CASE STUDY

The Results (Continued)

Passenger Throughputs

![Bar chart showing passenger throughputs for various stations.](attachment:image.png)
5 CASE STUDY

- Sensitivity Analysis

\[ \varepsilon = \frac{\Delta C / C}{\Delta x / x} \]

- Parameters:
  - Acceleration Efficiency
  - Deceleration Efficiency
  - Reaction Time
  - Length of Station Block
  - Length of Other Blocks
  - Distance between Head of Train to Starting Signal
  - Length of Train
  - Train Acceleration Rate
  - Train Deceleration Rate
  - Dwell Time
  - Cruising Speed

Elasticity graph showing the impact of each parameter on the sensitivity analysis.
Conclusions

- Model Applicability
  - The proposed framework can be applied to any kinds of rail systems

- Effective strategies to improve capacity
  - Change track station track layouts
  - Shorten signal block
  - Reduce dwell time
  - Enhance acceleration and deceleration performances
  - Operate all trains at the same speed
Recommendations

- Develop model to calculate signal headway for other kinds of signal systems (e.g., 4-aspect, cab signal)
- Computerize the model and the framework for easy applications
- Extend the model to consider single-track operations
THANK YOU FOR LISTENING