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

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Outline

1. Introduction
2. Literature Review
3. Basic Concept
4. Model Formulation
5. Case Study
6. Conclusion and Recommendations

1 INTRODUCTION

- **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

1 INTRODUCTION

- **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

2 LITERATURE REVIEW

Models for Capacity Analysis

	Analytical Model	Optimization Model	Simulation Model
Input Data	Few	Moderate	Many
Precision	Low	Moderate	High
Application	Strategy Analysis	Timetable Design	Timetable Validation
Cost	Low	Moderate	High
Easiness	Easy to Use	Relatively Difficult	Relatively Difficult
Dependence on System	Low	Moderate	High

2 LITERATURE REVIEW

- **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

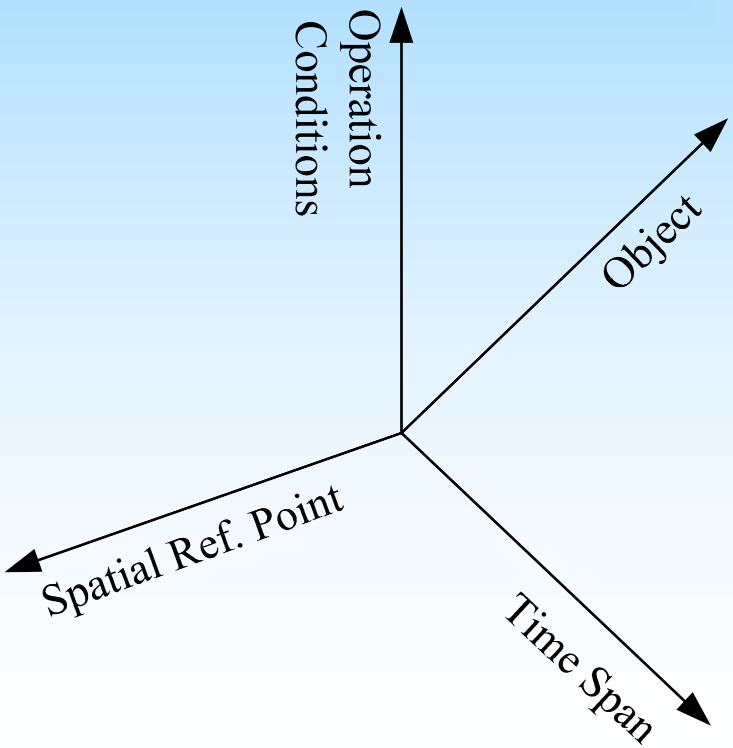
3 BASIC CONCEPT

☐ 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

3 BASIC CONCEPT

☐ Basic Elements for Defining Capacity

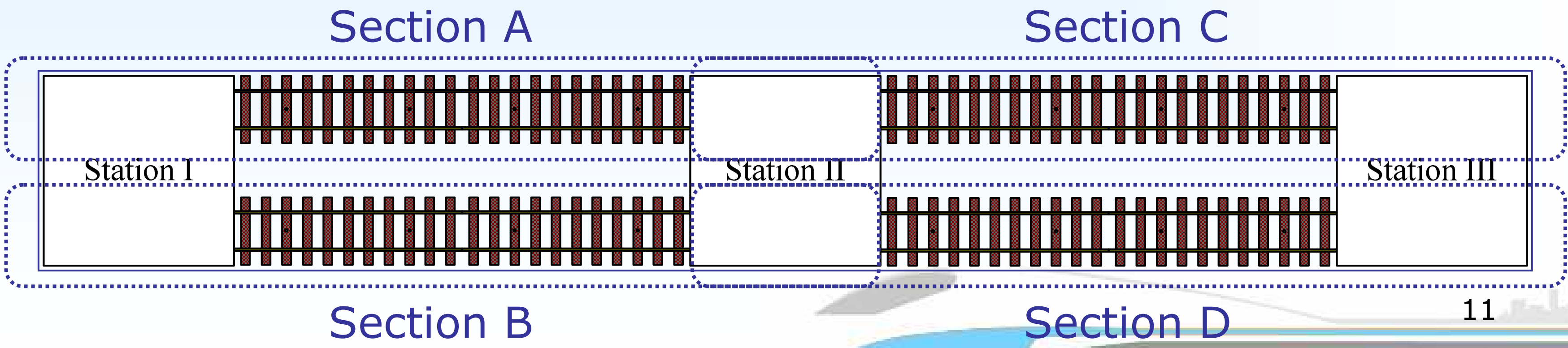


Dimension	Example
Operation Conditions	Railway Condition, Traffic Condition, Control Condition
Object Unit	Trains, Passengers, Passenger Spaces, tons
Time Span	Day, Hour
Spatial Ref. Point	Way, Station, Section, Turn Back, Junction, Line

4 MODEL FORMULATION

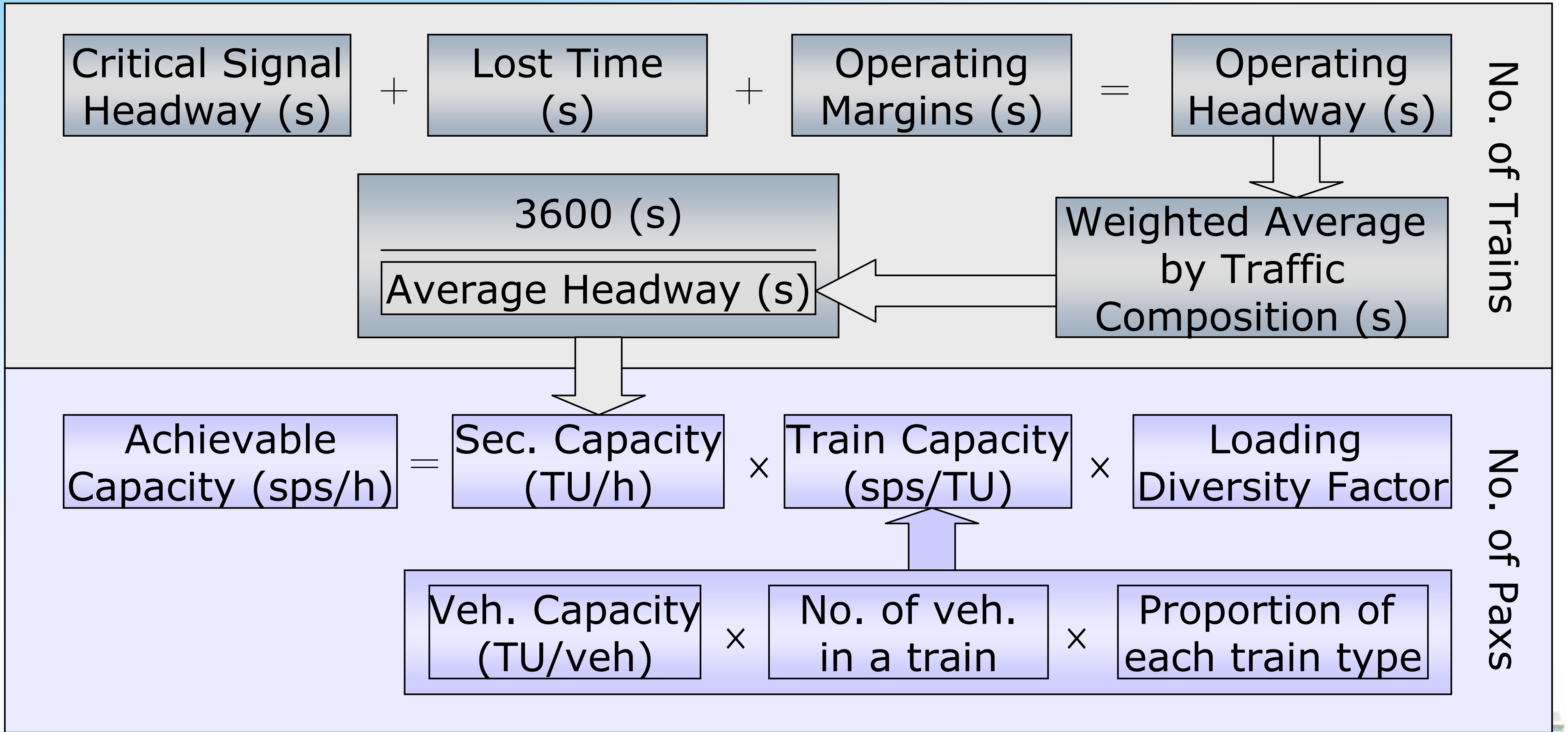
☐ Basic Unit for Capacity Analysis

- 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



4 MODEL FORMULATION

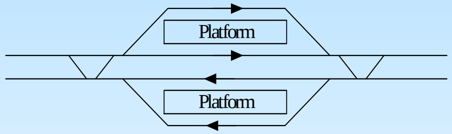
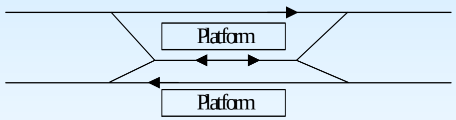
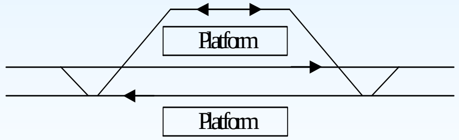
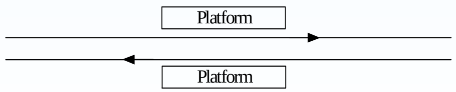
Critical Signal Headway

- 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

4 MODEL FORMULATION

□ Critical Signal Headway (cont.)

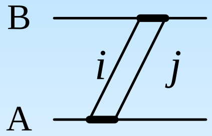
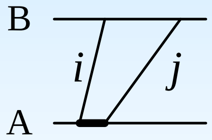
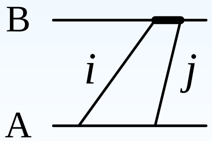
- Effects of Station Track Layouts

Type	Example of Track Layout	Signal Headway: Departure	Signal Headway: Arrival
I		$T_{s,D} = T_{s,D2}$	$T_{s,A} = T_{s,A2}$
II		$T_{s,D} = \frac{1}{3}T_{s,D1} + \frac{2}{3}T_{s,D2}$	$T_{s,A} = \frac{1}{3}T_{s,A1} + \frac{2}{3}T_{s,A2}$
III		$T_{s,D} = \frac{3}{4}T_{s,D1} + \frac{1}{4}T_{s,D2}$	$T_{s,A} = \frac{3}{4}T_{s,A1} + \frac{1}{4}T_{s,A2}$
IV		$T_{s,D} = T_{s,D1}$	$T_{s,A} = T_{s,A1}$

4 MODEL FORMULATION

☐ Critical Signal Headway (cont.)

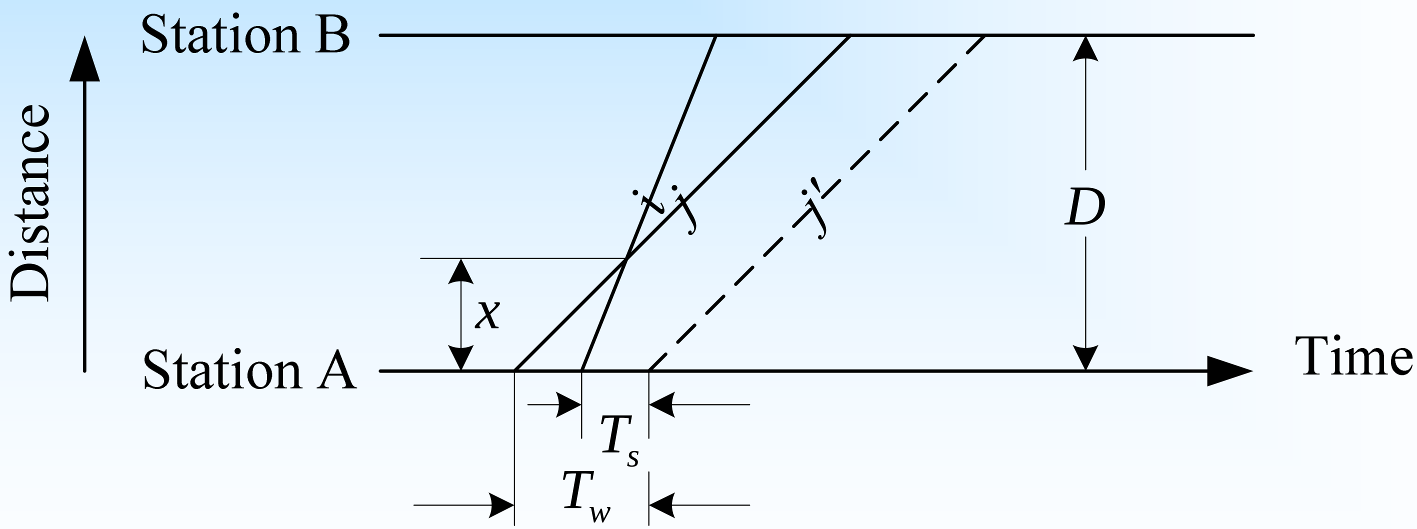
- Effects of Speed Variations

Condition	Critical Block Section	Critical Signal Headway
$t_i = t_j$		$T_s = \max(T_{s,D}^{A}, T_{s,A}^{B})$
$t_i < t_j$		$T_s = \max\left(T_{s,D}^{A}, T_{s,A}^{B} - \left(t_j - t_i\right)\right)$
$t_i > t_j$		$T_s = \max\left(T_{s,D}^{A} - \left(t_i - t_j\right), T_{s,A}^{B}\right)$

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

4 MODEL FORMULATION

- **Average Headway**
  - Weighted average headway by traffic composition
- **Hourly Train Throughput**
  - 3600 / average headway in seconds
- **Train Capacity**
  - Depending on train formation, seat arrangement, etc.

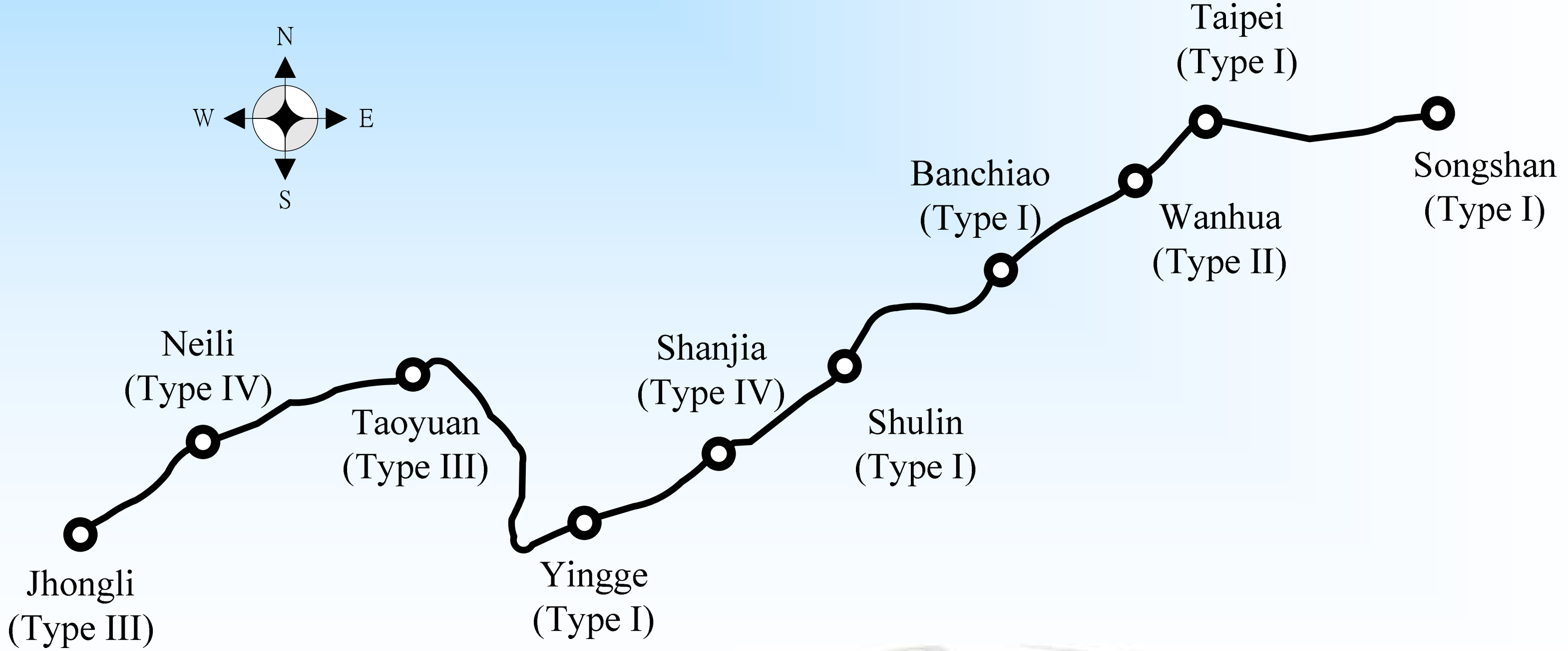
4 MODEL FORMULATION

- **Design Capacity**
  - Capacity from supply point of view
  - Train throughput X average train capacity
- **Achievable Capacity**
  - Demand is not uniformly distributed over time and space
  - Loading diversity factor (peak hour factor) is introduced
  - Design capacity X loading diversity factor

5 CASE STUDY

☐ Input Data

- Railway Conditions



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

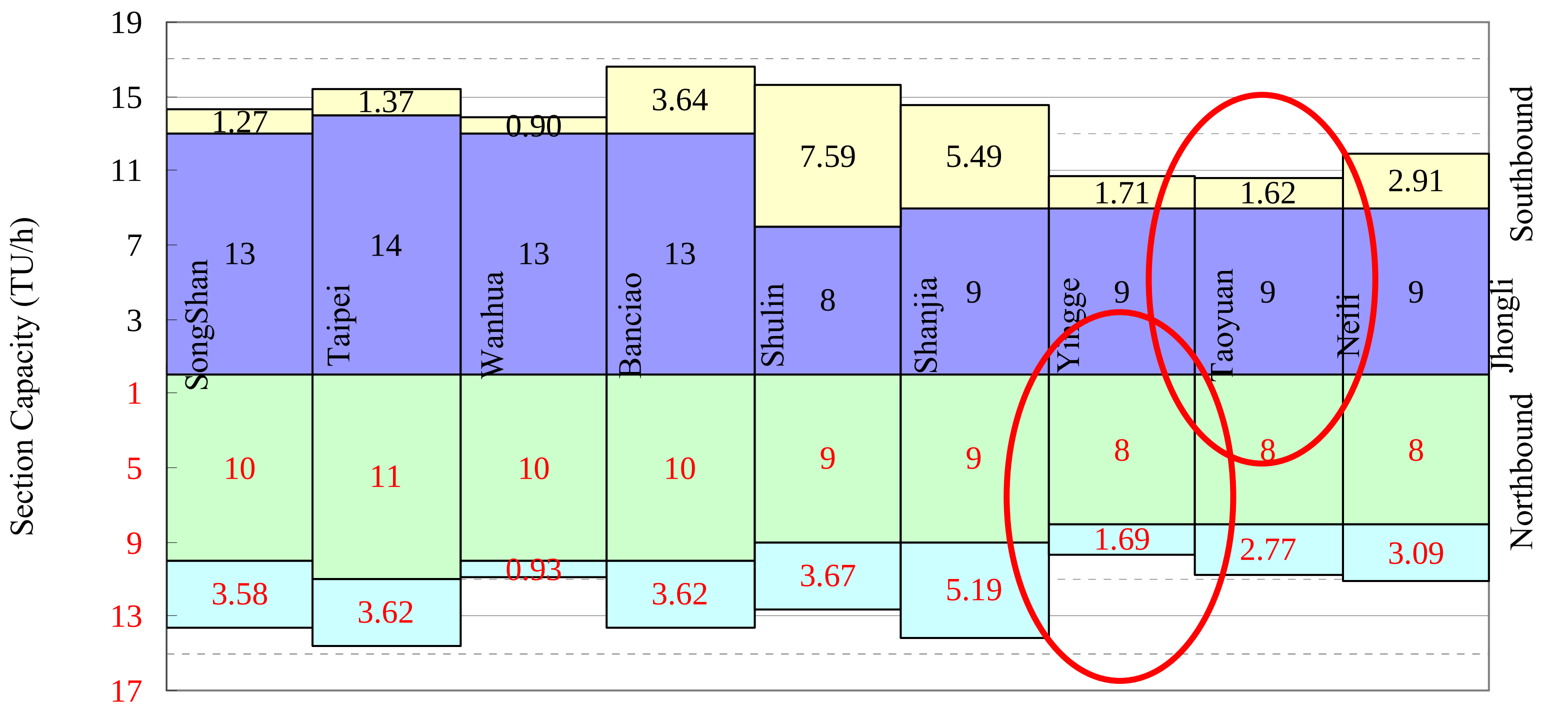
- Average Headway (Taoyuan to Neili)

Preceding train	Following train	T_s (s)	t_l (s)	t_m (s)	h_{ij} (s.)	Percentage
T.C Express	T.C Express	265.9	0	93.1	359.0	0.012
T.C Express	C.K Express	295.6	30.0	114.0	439.6	0.025
T.C Express	Commuter	239.7	7.5	86.5	333.7	0.074
C.K Express	T.C Express	229.1	30.0	90.7	349.8	0.025
C.K Express	C.K Express	318.8	0	111.6	430.4	0.049
C.K Express	Commuter	217.9	22.5	84.1	324.5	0.148
Commuter	T.C Express	237.4	7.5	85.7	330.6	0.074
Commuter	C.K Express	282.2	22.5	106.6	411.3	0.148
Commuter	Commuter	226.2	0	79.2	305.4	0.444
$\bar{h}$ =338.8 seconds, $C_o = \frac{3600}{338.8} = 10.62$ TU/h						

5 CASE STUDY

☐ The Results (Continued)

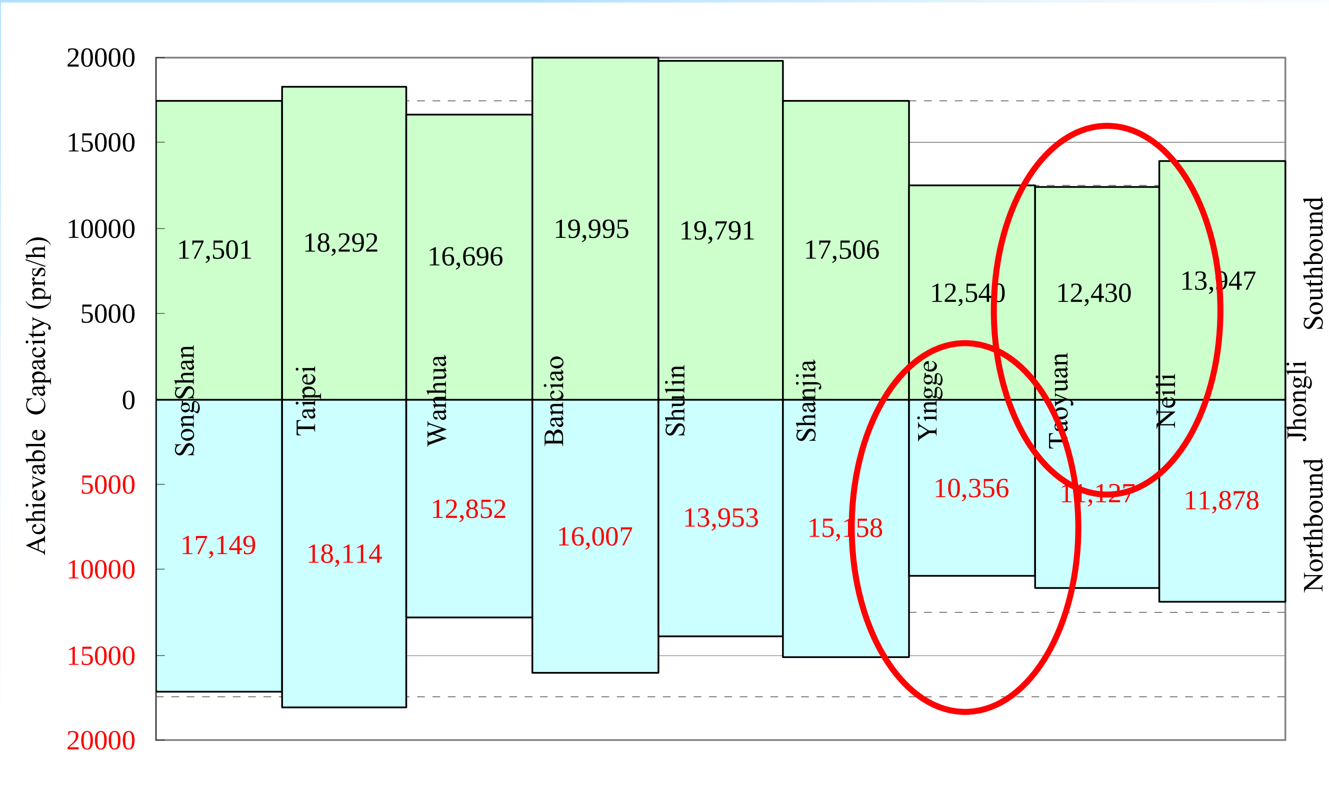
- Train Throughputs



5 CASE STUDY

☐ The Results (Continued)

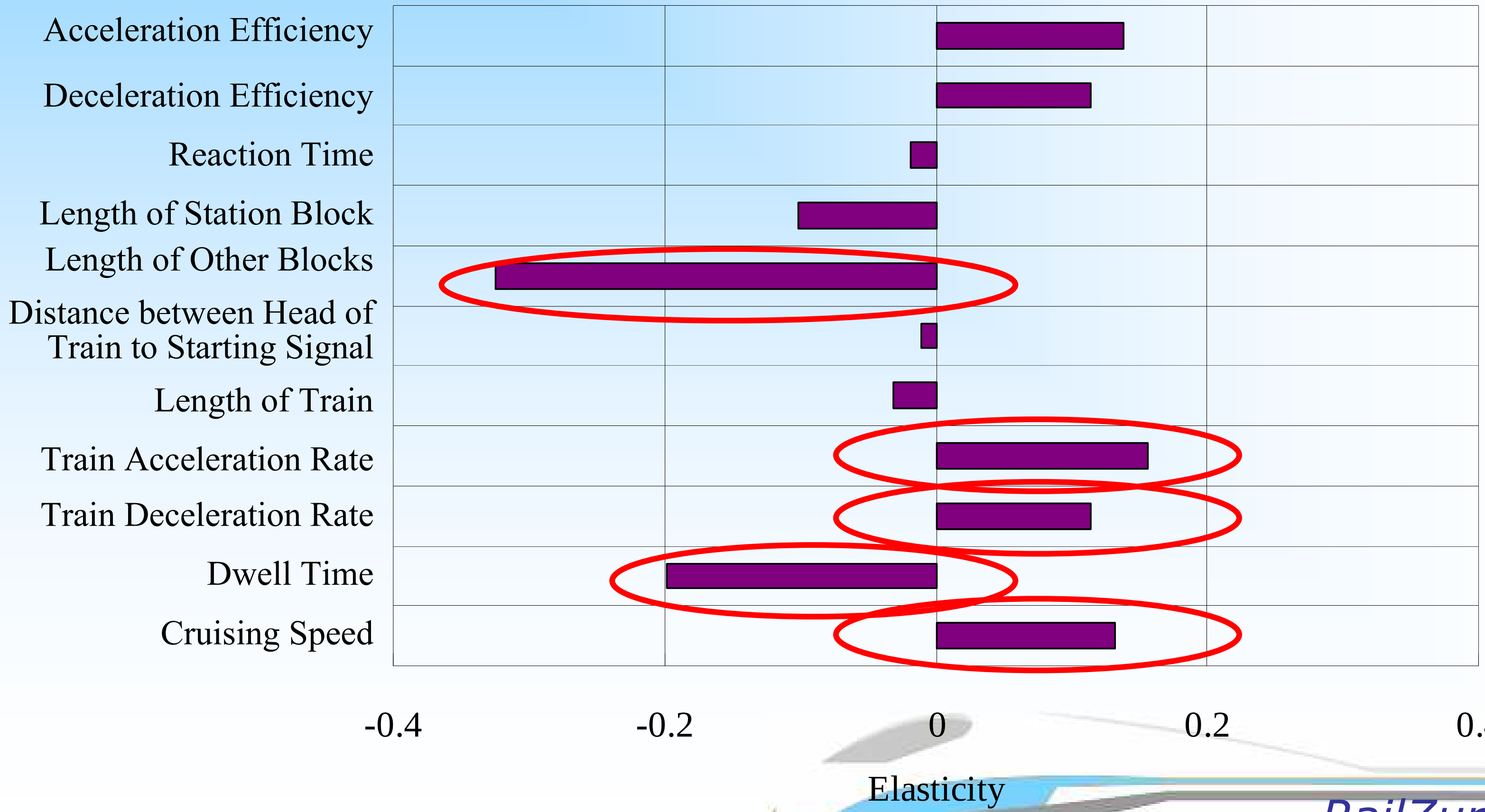
- Passenger Throughputs



5 CASE STUDY

☐ Sensitivity Analysis

$$\varepsilon = \frac{\Delta C / C}{\Delta x / x}$$



6 CONCLUSIONS AND RECOMMENDATIONS

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

6 CONCLUSIONS AND RECOMMENDATIONS

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

7 THANK YOU FOR LISTENING

Questions

Discussions

Feedback