Introduction to Railroad Capacity

Yung-Cheng (Rex) Lai
University of Illinois at Urbana-Champaign
Introduction to Rail Capacity

• Concepts:
  – Background
  – Importance
  – Measures

• What affects capacity?
  – Infrastructure factors
  – Traffic & operating factors

• Available Tools:
  – Theoretical approaches
  – Parametric models
  – Simulations
The North American railroad industry is facing capacity problems

Capacity and network efficiency have become more important as traffic volumes increase

- The estimated demand of 2035 will be 88% more than 2007
- Intermodal traffic is projected to increase at 3 ~ 6% per year for the next 5 years
- Capacity constraints are affecting network efficiency
- Problems range across many aspects of the railroad operation including:
  - Infrastructure
  - Equipment
  - Train dispatching, traffic mix
  - Human resources

Network Capacity must be increased

Source: Bechtle TRANSEARCH and EUWA Freight Analysis Framework Project
What is “capacity”?

Rail capacity is a loosely defined term that has numerous meanings.

1) General definition: Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan. (e.g. number of tons moved, average train speed, on-time-performance, maximum number of trains per day, etc.)

2) Track capacity: The highest volume (trains per day) that can be moved over a subdivision (plant) under a specified schedule and operating plan (traffic and operations) while not exceeding a defined threshold (over-the-road-time).

2a) Theoretical (Physical) Capacity: Maximum number of trains physically possible to squeeze through plant

2b) Practical Capacity: The practical limit of “representative traffic” volume that can be moved on a line while achieving a defined performance threshold. “representative traffic” reflects effects of train mix, priorities, fleeting, HP/ton “Performance threshold” can be maximum train crew on duty time, or minimum run time plus 10%, etc.
Why is capacity important?

• Railroads’ largest asset is their trackage and related infrastructure
  – Maximize the use of this asset to generate the largest revenue
  – Overcapacity may be as bad as insufficient capacity

• “You can’t manage what you can’t measure”

• Measurement and monitoring capacity enables more efficient utilization of this asset

• Objectives
  – Improve track asset utilization
  – Increase service reliability
  – Reduce capital and operating costs

• Optimal balance among competing objectives
Metrics of Network Capacity

- **Average Train Speed** – “over-the-road train speed”. Train Speed measures the line-haul movement between terminals. The average speed is calculated by *dividing train-miles by total hours operated*, excluding terminal dwell time, time for local pickup and delivery, and the time shipments spend in storage yards.

System-wide Average Train Speeds

[Graph showing system-wide average train speeds for BNSF, CPR, CSX, NS, and UP from May 1, 2006, to April 1, 2007.](http://www.railroadpm.org/)
Metrics of Network Capacity

- **Average Delay** (hours per day) – “Meet & Pass Delay”. The time spent for meets and passes without the dwell or wait on schedule. The Average Delay tells us how much total delay is being experienced, and that’s a useful measure of system congestion. It may also help measure things like environmental impacts from emissions.

  (dwell time: amount of time that a train stops at a point for planned work, e.g. switching an industry, or entraining or detraining passengers at a depot.)

- **Delay Ratio** (%) – “Meet & Pass Delay Percentage”. The proportion of running that a train is stopped for meets and passes with other trains, excluding dwell or waiting on schedule. Delay ratio represents normalized delay which is a measure of how much delay any given train is likely to experience.

- **On Time Percentage** (%) – the percentage of trains that complete their overall run on or ahead of schedule.
Meet and Pass

- Single track poses significantly more challenges for capacity
- No longer simply limited by train spacing
- Must consider “meets” of trains traveling in opposite direction
- These impose constraints on schedule
Meets on Single Track
Meets on Single Track
Meets on Single Track

Meet Delay

T_3
Passing on Single Track
Passing on Single Track

![Diagram of passing on single track with time axis labeled $T_2$ and pass delay highlighted.](image)
Increase Traffic Volume will Increase Meets & Passes
Increase Traffic Volume will Increase Meets & Passes

ST, siding every 21.4 miles

Bidirectional running, DT

Directional running, DT
General Relationship between Delay & Volume

\[ \text{Train Delay} = Ae^{BV} \]

Where:
- \( A \) = Coefficient determined by Plant, Traffic, Operating parameters
- \( B \) = Constant
- \( V \) = Traffic Volume
What affects capacity?

• Infrastructure factors:
  – Meet & Pass Planning Point Spacing (MPPPS)
  – Signal Spacing (SS)
  – Percent Double Track (% DT)

• Traffic and operating factors:
  – Traffic Peaking Factor (TPF)
  – Priority Probability (PP)
  – Speed Ratio (SR)
  – Average Speed (AS)
  – Track Outages (TO’s)
  – Temporary Slow Orders (TSO’s)
Infrastructure Factors

- Meet Pass Planning Point Spacing (MPPPS):

\[
MPPPS = \frac{\text{Length of Subdivision}}{\# \text{ of MPPP} + 1}
\]
Infrastructure Factors

- Signal Spacing (SS):

\[ SS = \frac{\text{Length of Subdivision}}{\# \text{ of Signals} + 1} \]
Infrastructure Factors

• Percent Double Track (% DT):

\[
\% \text{ DT} = \frac{\text{Miles of Double Track}}{\text{Length of Subdivision}} \times 100
\]
Single Track Bi-directional Running
Double Track Directional Running
Bi-Directional Running Reduces Capacity

Separated Railroads contend with bi-directional running.

- **Union Pacific Line**
- **Southern Pacific Line**

- High-volume route
- Each railroad was operating single track with passing sidings between St. Louis and Texas
- Elimination of bi-directional running was one of the big pay-offs in the UP-SP merger
Directional Running After Merger

- Eliminate “meet delay”
Traffic Factors

• Traffic Peaking Factor (TPF):

\[
TPF = \frac{\text{Maximum Trains in 4 hours}}{\text{Average Trains in 4 hours}}
\]

• Priority Probability (PP):

\[
PP = \frac{1}{T} \sum_{i=2}^{N} \left( \frac{C_i}{(T-1)} \sum_{j=1}^{i-1} C_j \right) = \frac{1}{T} \left( \frac{C_2}{(T-1)} \times C_1 + \frac{C_3}{(T-1)} \times (C_1 + C_2) \right)
\]

Where:
- \( N \) = Number of priority classes
- \( T \) = Daily number of trains
- \( C_i, C_j \) = Number of \( i \)th, \( j \)th priority class trains
Traffic Factors

• **Speed Ratio (SR):**

\[
SR = \frac{\text{Fastest Train Speed}}{\text{Slowest Train Speed}}
\]

• **Average Speed (AS):**

\[
AS = \frac{\sum_{i=1}^{N} C_i V_i}{\sum_{i=1}^{N} C_i}
\]

Where:

- \( V_i \) = Average speed of jth type train
- \( C_i, C_j \) = Number of ith, jth priority class trains

The Most Important Factor
Types of Trains

• Passenger
  – Rapid Transit
  – Commuter Rail
  – Intercity
  – High-speed Rail

• Freight
  – Intermodal
  – Manifest or mixed freight
  – Unit trains
  – Local or road switching
Intermodal

- High-priority, time sensitive traffic
- Rarely switched enroute
- Powered for speed (≥ 2HP/ton)
- Typical length: 6,000’ - 8,500’
- Maximum speed: 60 - 70 mph
- Distance traveled: ≥ 700 miles
Manifest Freight

- Mix of cars, commodities, origins and destinations
- Mix of loads and empties
- Less time-sensitive traffic
- May switch enroute at certain areas
- HP/ton = 0.9 to 1.2
- Typical weight: 6,000 - 8,000 tons
- Operates up to 60 mph
- Distance traveled ranges from 100 miles to >1,000
Unit Trains

- Bulk commodity freight (coal, grain, minerals)
- Moves as a unit from origin to destination
- Typical weight: 12,000 - 15,000 tons
- 132 - 145 tons per car
- Maximum speed ca 45 mph
- Distance traveled up to 2,000 miles
Locals & Road-switchers

- Lowest priority
- Pick up and set out of cars at customer facilities
  - may take half to several hours at a plant
  - often leave cars on main while switching
  - Typical length: up to 35 cars (or more)
  - Distance traveled typically not more than 60 miles
Recall that Different Trains Have Different Stopping Characteristics

- Both weight and speed will affect stopping distance
- This affects signal spacing, in particular, requiring block length to accommodate longest stopping distance
Speed & Variances of Different Types of Trains

![Graph showing average speed (mph) for different types of trains: Passenger, Intermodal, Manifest, Unit.]

- Passenger: Average speed with variance
- Intermodal: Average speed with variance
- Manifest: Average speed with variance
- Unit: Average speed with variance
The Impact of Different Type of Trains

[Graph showing the impact of different types of trains on time and distance.]
Operating Factors

• Track Outages (TO’s)
  – Reduce the available time to run trains

• Temporary Slow Orders (TSO’s)
  – Reduce the train speed
Options to increase line capacity

Operations options:
- Increase average speed
- Reduce traffic peaking
- Reduce the variability in speed
- Reduce number of meets & passes

Infrastructure options:
- Line (links):
  - Reduce traffic control block length
  - Add or lengthen passing sidings
  - Additional tracks
- Junctions (nodes):
  - Improve junction design
  - Grade separation

Operations options should generally be considered first because they are typically less expensive and faster to implement than new infrastructure.
Theoretical models are the simplest among the three, and can often be computed manually:

- Quick evaluation of relative effects

Simulation models mimic train dispatcher logic, and is the most sophisticated and computationally intensive method:

- Closest representation of the actual operations

Parametric models are developed from simulation and focus on the key elements of line capacity:

- Fill the gap between simple theoretical model and detailed simulation

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<th>Computation Efficiency</th>
<th>Accuracy</th>
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<tr>
<td>Parametric</td>
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<td></td>
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<tr>
<td>Simulation</td>
<td></td>
<td>✓</td>
</tr>
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</table>
Notable Capacity Analysis Tools

Theoretical models:
- AREA (1947), Poole (1962), ABA (1972), AREMA (2002)
- UIC Leaflet 406

Simulation models:
- Rail Traffic Controller (RTC)
- CN Route Capacity Model (RCM)

The parametric models:
- PMM model (1975)
- CN parametric model (1999)
Theoretical Line Capacity

• Theoretical capacity enables mathematical comparison of the *relative* capacity of different systems

• The actual capacity of a line will be less than theoretical capacity and is subject to a variety of factors

• Two theoretical line capacity models:
  – Maximum throughput method for double track capacity
  – Return grid method for single track capacity
Maximum Throughput Computation

• Capacity is calculated by *Maximum Throughput* which represents the maximum traffic flow that a rail line can accommodate under ideal condition.

• Assumptions:
  – Same characteristic trains
  – Trains operate at “Normal” speed
  – Train movement is directional
  – No meets or passes
Maximum Throughput Computation

• Maximum Throughput: the maximum traffic flow that a rail line can accommodate under ideal condition

\[ N = \frac{24 \times 60}{H_{\text{min}}} \]

Where:
- \( N \) = Number of trains per day
- \( H_{\text{min}} \) = Minimum headway (minutes)
Minimum Headway – Signal System

• Minimum Headway: The minimum time that the dispatcher can send a train following a leading train without any restriction in speed

\[ H_{\text{min}} = \frac{L_B(S - 1) + L_T}{V} \times 60 \]

Where:

- \( H_{\text{min}} \) = Minimum headway (minutes)
- \( L_B \) = Block length (stopping distance of the design train in miles)
- \( L_T \) = Train length (miles)
- \( S \) = Number of aspects
- \( V \) = Track speed (mph)
Minimum Headway – Blocking Time

**Blocking time:**
the time interval in which a section of track is exclusively allocated to a train and therefore blocked for other trains
Blocking Time "Stairway"
Signal and Line Headway
### Maximum Throughput Example

#### 150-car Freight Train:
- Train Length: 1.5 miles
- Stopping Distance: 8,000 (ft)
- Speed: 50 mph

#### 8-car Passenger Train:
- Train Length: 650 feet
- Stopping Distance: 6,000 (ft)
- Speed: 79 mph

<table>
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<tr>
<th>Type of Train</th>
<th>Block Length (miles)</th>
<th>Number of Aspects</th>
<th>Maximum Throughput (trains/day)</th>
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<tbody>
<tr>
<td>Freight Train</td>
<td>1.52</td>
<td>3</td>
<td>265</td>
</tr>
<tr>
<td>Passenger Train</td>
<td>1.14</td>
<td>3</td>
<td>791</td>
</tr>
</tbody>
</table>
Return Grid Method

• Developed for computing single track capacity
• Used in CN to perform very quick capacity evaluation
• Assumptions:
  – Track speeds based on current timetable
  – Train transit times from TPC based on specific HP to ton ratio
  – No pass

\[
N = \left( \frac{24 \times 60}{E_t + W_t + V_t} \right) \times E_f \times D \times 2
\]

Where:

\( E_t, W_t \) = Eastbound, westbound transit time
\( V_t \) = Additional time due to acceleration, deceleration, etc.
\( E_f \) = System efficiency
  (60, 70, & 80% for train order, ABS & CTC, respectively)
\( D \) = Discount factor for practical capacity
Time 0- Start

Time 1 - E/B Grid
Train 1 @ Siding B

Time 2 - V-Time
Train 2 accelerate from stop

Time 3 - W/B Grid
Train 2 @ Siding A
Siding Grid Capacity

Available Track Time to move trains

\[
N = \left( \frac{24 \times 60}{E_t + W_t + V_t} \right) \times E_f \times D \times 2
\]

\[
\frac{\text{Available Track Time to move trains}}{\text{Time for pair of trains to move between sidings}} \times \text{Train Control Efficiency} \times \text{Theoretical vs. Practical} \times 2 \text{ trains per pair} = \text{Trains / Day}
\]
Return Grid Example

- Train Lengths: 10,000 ft (1 HP/ton)
- Time for pair of trains to move between sidings = $(E/B \text{ time } + W/B \text{ time}) + (\text{time for train to pass through siding})$

$$N = \left( \frac{24 \times 60}{12 + 14 + 15} \right) \times 80\% \times \frac{2}{3} \times 2 = 37 \text{ (trains/day)}$$

- Capacity Impacted by
  - Train Speed
  - Distance between long sidings for long trains
  - Delay at siding
Train Delay  = $A e^{BV}$

Where:
- $A$ = Coefficient determined by Plant, Traffic, Operating parameters
- $B$ = Constant
- $V$ = Traffic Volume
Railway Simulation Tools

• Railway simulation tools intend to dispatch trains using the same elements as a human dispatcher

• They account for different equipment types, train consists, train handling characteristics, terrain and track conditions

• Common uses of Simulation Tools:
  – Develop operating plans
  – Diagnose bottlenecks and recommend schedule changes
  – Evaluate various capital improvement scenarios
  – Assess the impact of adding new trains to a network
RTC ARCHITECTURE

NETWORK

TRAINS

ORIGIN/DESTINATION
EN ROUTE DWELLS
REQUESTED SCHEDULES
LOCOMOTIVE CONSIST
TRAILING CONSIST
CREWS
INITIAL TRAIN DELAY COSTS

FORMS/BULLETINS

TPC

DYNAMIC TRAIN DELAY COST COMPUTATION

MEET-PASS LOGIC

TRAIN PLAN

ANIMATION
TIME-DISTANCE STRINGLINE
TIMETABLES
TRACK OCCUPANCY CHARTS
REPORTS

INPUT
INTEGRATED N-TRAIN LOGIC
OUTPUT
Strategic Capacity Planning Process

Step 1: Run and compare base (current) case and future case without any capacity improvements \(\rightarrow\) determine whether improvement is necessary

Step 2: If capacity improvement is necessary, set up the goal performance and identify bottlenecks in the future case

Step 3: Propose alternatives (scenarios) to meet the goal by reducing congestion

Step 4: Conduct scenarios analysis of proposed alternatives and evaluate the results

Step 5: The best alternative is the one satisfying the goal performance with the minimum cost

Examples:
- Freight railroads’ capacity planning to meet the future demand
- Public agency or passenger rail propose shared-use corridor
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Presentation Author
Yung-Cheng (Rex) Lai
Railroad Engineering Program
Civil & Environmental Engineering Department
University of Illinois at Urbana-Champaign
B118 Newmark Civil Engineering Lab, MC-250
Urbana, IL  61801
(217) 244-6063
<lai3@uiuc.edu>

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