How do you Spell Capacity on a Railroad?
- A Primer on Railroad Operations Design

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Outline

- Introduction
- Basic Rail Capacity Concepts
- Analytical Models of Railway Capacity
- Parametric Models
- Simulation Models
- Optimization Models
- Other Considerations and Expansion Strategies
Suggested Definition of Rail Capacity

The maximum number of trains that can be moved between two locations in a day without exceeding a predefined level of service.
Fields Related to Capacity

- Analytics
- Data mining
- Network optimization
- Queuing theory
- Regression modeling
- Risk modeling
- Simulation
- Utility models
Elements in Determining Rail Capacity

- **Line Capacity**: number of tracks; type and spacing of control system; number, spacing, and length of sidings; mix of train types; operating and maintenance plans
- **Yard Capacity**: total acreage; number of tracks; container storage slots
- **Crew Capacity**: available crew starts; yard crews; maintenance crews
- **Equipment Capacity**: locomotives; railcars; containers/trailers
Other Factors Determining Line Capacity

- **Physical Track Layout**
  - Number of tracks
  - Type of signals
  - Number and spacing of sidings

- **Operating Plan**
  - Schedules
  - Type of service

- **Train makeup**
  - Number and horsepower of locomotives
  - Train length and weight

- **Geography**
  - Mountains
  - Tunnels
  - Bridges
## Railway Capacity Metrics

<table>
<thead>
<tr>
<th>Amount Moved</th>
<th>Reliability</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trains</td>
<td>Distribution of Arrival Times</td>
<td>Terminal Dwell</td>
</tr>
<tr>
<td>Railcars</td>
<td>Average Delay</td>
<td>Blocking Time</td>
</tr>
<tr>
<td>Gross Tons</td>
<td>Standard Deviation of Delay</td>
<td>Signal Wake</td>
</tr>
<tr>
<td>Revenue Tons</td>
<td>On Time Performance</td>
<td>Train Miles/Track Mile</td>
</tr>
<tr>
<td>Passengers</td>
<td>Right Car Right Train</td>
<td>Cycle Time</td>
</tr>
<tr>
<td>TEUs</td>
<td>Crew Expirations</td>
<td>Trainsets or Railcars On-Line</td>
</tr>
<tr>
<td>(Per Year)</td>
<td>Velocity</td>
<td>Track Occupation</td>
</tr>
<tr>
<td>(Per Day)</td>
<td></td>
<td>Train Density</td>
</tr>
<tr>
<td>(Per Hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Per Peak Hour)</td>
<td></td>
<td></td>
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</tbody>
</table>
Types of Capacity

- **Practical (Effective) Capacity**: Ability to move traffic at an “acceptable” level of service
- **Economic Capacity**: The level of traffic at which the costs of additional traffic outweighs the benefits
- **Engineering Capacity**: The maximum amount moved before the system ceases to function
- **Ultimate (Maximum) Capacity**: Breakdown conditions at maximum train density. The system has ceased to function and all signals are red
Maximum Versus Effective Capacity

- Transportation firms can never utilize a facility 100% of the time
  - Maintenance
  - Weather
  - Peaking of traffic volumes
  - Disruptions and recoverability
  - Normal variability in operational conditions

- Industry practices call for standards to maintain fluidity of operations and avoid major issues at chokepoints
  - Useable (effective) capacity is 70% to 80% of the maximum (theoretical) capacity
  - Utilizing the capacity buffer between effective and maximum capacity results in deferred maintenance, reduced ability to react to variability with increasing recovery time, significant reduction in reliability
Increasing Demands on Rail Network

Forecasted Growth of Freight Trains Per Day
2035 – Based on US DOT Freight Analysis Framework

Problems of Capacity Shortages

- Inability to handle more traffic
- Decreasing level of service
- Diminished ability to recover from a disruption
- Limited windows for track maintenance
- Increase time in yards, terminals and stations
- Increase cycle times
- Increase number of trainsets, rolling stock
- Increase number of crews (hours of service limitations)
- All of the above increase costs
Capacity is an Expensive Resource

- Railway infrastructure is capital intensive and a long-term investment
- Capacity lags behind changing demands
Levels of Capacity Analysis

- Transportation Network
  - Railroad Network
  - Subdivision or Line
  - Yards & Terminals
  - Stations & Platforms
  - Interlockings & Junctions
Modeling Rail Capacity

- Rail Capacity Definition
- Stringline Diagrams
- Parametric Models
- Train Performance Calculators
- Train Dispatching Simulation
Unlike highways, there is no standard railroad capacity model

- The complex nature of railroad operations and limited research funding has prevented a universal capacity model from being developed
- Currently several different models are in use
Levels of Effort in Modeling Rail Capacity

- **Initial Estimation**
  - "Back of the envelope" methods
  - Expert with basic knowledge of number of tracks, type of signals, and special conditions (e.g. mountainous terrain)
  - Useful for quick assessment of a single corridor or facility

- **Planning Models**
  - Variety of methods, requires more data than back of the envelope but less than a full simulation
  - Parametric (statistical based) models stem from 1975 FRA work and the CN model (Krueger, 1999)
  - "Paper" simulations (now evolved to spreadsheets) are also used for capacity estimation

- **Simulation**
  - Uses a commercial rail simulation product (RTC, RAILS, FastTrack)
  - Requires precise network layout (tracks, sidings, interlockings, signals, etc.)
  - Requires knowledge of operating plan: trains that will be run and schedules
  - Initial setup is expensive
Level of Service to Measure Capacity

- Higher delays correspond to a lower level of service (LOS)

- Maximum theoretical train volumes are never reached due to deteriorated level of service

- Acceptable level of service establishes maximum train volume

Different Traffic and Track Configurations will Change Delay-Volume Relationship

Acceptable Delay

Delay (mins)

Volume (Trains/Day)
Track Configuration

- Number of tracks
- Siding length
- Siding spacing (distance & time)
- Crossover spacing
  - Single crossovers
  - Universal crossovers
  - Parallel crossovers
- Geometry
  - Grade
  - Curvature
Track Attributes Were used to Determine Capacity

Type of Control System
CTC=Blue, ABS=Green, Manual=Red

Number of Tracks
Two or More Tracks=Blue, Single Track=Tan

Heterogeneous Operations and Capacity

- Simple headway and grid models only work when all trains operate at the same speed
- Actual trains have different
  - Operating speed
  - Acceleration and braking characteristics
  - Priority
  - Station stopping patterns
- Particularly apparent where passenger and freight operations share track infrastructure
- From a capacity perspective:
  1 freight train $\neq$ 1 passenger train
- These differences decrease capacity and require more complicated capacity analysis tools
Parametric Models

- **Parametric Models** are developed from statistical analysis of collected operating or simulation data.

- Key infrastructure and operating parameters are identified to predict a delay-volume curve.

- Attributes include:
  - Average speed
  - Speed ratio
  - Priority
  - Peaking
  - Siding spacing and uniformity
  - Percent double track
  - Signal spacing

- FRA and CN have well-known parametric models.
Limitations of Parametric Models

- The Canadian National parametric model is the best known example
  - It was designed for single track corridors
  - Does not handle complex track configurations

- FRA has sponsored research into improving parametric models for more complex track layouts

- Parametric models are best used for high-level national or regional modeling to identify potential problem areas

- Detailed capacity analysis is done with simulation
**CN Parametric Model Example**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Speed</td>
<td>44.4 mph</td>
</tr>
<tr>
<td>Speed Ratio</td>
<td>1.113</td>
</tr>
<tr>
<td>Priority</td>
<td>0.342</td>
</tr>
<tr>
<td>Peaking</td>
<td>1.727</td>
</tr>
<tr>
<td>Siding Spacing</td>
<td>7.77 miles</td>
</tr>
<tr>
<td>Uniformity</td>
<td>0.49</td>
</tr>
<tr>
<td>Signal Spacing</td>
<td>0.93</td>
</tr>
<tr>
<td>% Double Track</td>
<td>50</td>
</tr>
</tbody>
</table>

![Graph](https://via.placeholder.com/150)

Railway Simulation Tools

- Calculate train movements and make decisions under the same rules as railroad dispatchers
- 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
- Many simulation models are available depending on the purpose and task of the study
Types of Simulation Tools

- Passenger timetable development (passenger)
  - OpenTrack
  - Viriato

- Specify timetable and identify conflicts
  - RailSYS
  - RailEval

- Non-timetable (freight) and resolve conflicts with dispatching logic
  - Rail Traffic Controller
Train Dispatching Simulation
Types of Outputs

- Stringline (time-distance plot)
- User configurable reports
- TPC profiles
- Track occupancy charts
- Animation of simulation
Stringlines are a Primary Analytical Tool Used Worldwide
Green & Blue = Passenger, Red = Freight, Brown = Locals

Software Products Allow:
• Selecting timeframes, corridors, and trains
• Building or adjusting schedules by adding and dragging strings
Types of Reports

- Individual train "logs"
  - Scheduled & unscheduled delays
    - In total
    - By train type
    - By location
- Statistical analyses
  - Distribution of trip times
  - Locomotive-miles
  - Distribution of delays
    - Used to determine if plant is balanced
- Operating costs
- Timetables

![Timetable Diagram]

- Simplification of Prototype
- Only required information for model operators
- Times are departure times. Unless noted by Ar=arriving time
- No meets: Scheduled meets have little "Play Value" Dispatcher controls meets
- Early RR’s reuse equipment
- Mid Day Thru #1/2
- Morning Local #11/12
- Evening Local #13/14
- Fast Times: 6:1 resulted in 30 minutes to go 90 miles
- Indicates no stop
- No Freights: String diagrams and such can be used. We run as extra’s under dispatchers discretion
Animation of Results

Source: www.berkeleysimulation.com
Animation of Results – Yard with Industrial Leads

The Iterative Planning Process
Using Computer Modeling

- Develop “base case” traffic
  - Track configuration, signals & other physical attributes
  - Operating plan
- Develop alternative scenarios (changes to physical plant or operating plan)
- Compare alternative scenario to base, or to other alternative
The Iterative Planning Process
Using Computer Modeling - 2

- Inject track maintenance and operating failures at critical points, and determine if plant still works.
  - If not, refine plant some more and re-run
    » First without perturbations
    » Then with perturbations
- Select alternatives that meet operating objectives
  - If none, refine alternatives & re-run
  - Balanced plant is achieved when delays are evenly distributed
Limitations of Simulation Models

- Data and time intensive
- Must validate to actual
- Yard operations are modeled separately (hump operations, intermodal lifts, etc.)
- Resource constraints (crews, locomotives, etc..) are largely ignored
- Models do not look beyond study area to the rest of the network
- Even detailed simulation requires simplifying assumptions
Optimization Models

- Identify required system settings to achieve an optimal level of performance
- Can become computationally complex for large railway networks with multiple train types
- Example applications
  - Passenger timetable development
  - Station platform and track assignment
  - Rolling stock and crew cycles
  - Infrastructure investments for running time improvement on shared corridors
Strategies to Increase Capacity

- Operations options:
  - Increase average speed
  - Reduce traffic peaking
  - Reduce the variability in speed
  - Reduce number of meets & passes
  - Increase length & weight of trains
  - Improved acceleration and braking
  - Scheduling

- Infrastructure options:
  - Add or lengthen passing sidings
  - Additional tracks
  - Add staging and terminal tracks
  - Add station platforms
  - Improve junction design
  - Grade separations
Other Capacity Factors

- Mainline capacity consumed by
  - Local service to freight rail customers
  - Deadhead and repositioning moves
  - Passenger boarding delays
  - Locomotive and rolling stock failures
  - Track inspection
  - Track maintenance

- Difference between practical and engineering capacity
But at what cost?

- New passing siding
  - $8 million and up

- Second main track
  - $1 million per mile for rail, ties and ballast
  - $4-6 million per mile depending on embankment, drainage and signals
  - Bridges, grade separations and tunnels can quickly increase costs
Rail Capacity Research Needs

- Models that capture yard-mainline interaction
- Predicting the impact of higher speed passenger and freight trains on the same corridor
- Creating new theoretical & parametric models
Thank You!