Using the RTC Simulation Model to Evaluate Effects of Operating Heterogeneity on Railway Capacity

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September 12, 2008
The William W. Hay Railroad Engineering Seminar Series
Outline

• Background
• Methodology
• Freight Heterogeneity Study
• Passenger Heterogeneity Study
• Future Work
What is Railroad Capacity?

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 with acceptable punctuality. (e.g. number of tons moved, average train speed, on-time-performance, maximum number of trains per day, etc.)

Theoretical Capacity:

- Maximum number of trains physically possible to move across a rail line under ideal conditions

Practical Capacity:

- Maximum number of trains possible accounting for actual conditions and achieving a reasonable level of reliability
Factors Affecting Capacity

**Infrastructure**
- Siding length and spacing
- Crossover spacing
- Number of tracks
- Signal and traffic control system
- Grade
- Curvature

**Operations**
- Average and variability in speed
- Schedule stability
- Terminal efficiency
- Heterogeneity in train type
The North American railroad industry is facing capacity constraints

- Between 2000 and 2005 the US railroads revenue ton miles increased by over 13%.
- AASHTO predicts the demand for freight rail services will increase 84% based on ton-miles by 2035.
- In 2007 Amtrak’s ridership had its fifth straight year of growth with an increase of 6.3%.
The North American railroad industry is facing capacity problems

Future Volumes Compared to Future Capacity
In 2035 without Improvements
Capital Expansion is Costly

• An investment of $148 billion (in 2007 dollars) is required for infrastructure expansion over the next 28 years to meet the USDOT’s forecasted demand

• Class I capital expenditures for infrastructure expansion totaled:
  – $1.1 billion in 2005
  – $1.4 billion in 2006
  – $1.9 billion in 2007 (estimate)
Understanding Operations is Necessary for Effective Capacity Planning

- Consideration of how operational practices affect demand on infrastructure is critical
- Heterogeneity in train and traffic characteristics is a key aspect of railway operations that affects capacity

What is train type heterogeneity?
- Different trains have substantially different operating characteristics including: speed, acceleration, braking distances and dispatching priorities
Impact of Heterogeneous Train Types on Capacity
Models Used in this Study

• **CN Parametric Model**
  - *Parametric models* are developed using simulation to identify critical parametric relationships and focus on the key elements of line capacity:
    • Fill the gap between simple theoretical models and detailed simulations
    • Quickly evaluate capacity characteristics of line

• **Rail Traffic Controller (RTC)**
  - *Simulation models* include detailed infrastructure configuration and mimics train dispatcher logic
    • Closest representation of actual operations
    • Sophisticated and computationally intensive
CN Parametric Model

- CN Parametric Model uses infrastructure and operating parameters to predict a delay-volume curve
  - Attributes include
    - Average speed
    - Speed ratio
    - Priority
    - Peaking
    - Siding spacing and uniformity
    - Percent double track
    - Signal spacing
Rail Traffic Controller (RTC)

- Rail Traffic Controller (RTC) from Berkeley Simulation Software®
  - Dispatch simulation software
  - Allows modeling and simulation of multiple traffic scenarios
  - Variety of types of outputs available
Industry-Standard Software

CREATE

California High-Speed Rail Authority

Los Angeles—San Diego—San Luis Obispo Rail Corridor Agency
Network Inputs

- Track layout
  - Sidings
  - Turnouts
  - Crossovers
  - Interlockings
  - Switch types
- Signals
  - Absolute and permissive
Train Inputs

- Locomotives
  - Type
  - Number
  - Position in train

- Consists
  - Loads
  - Empties
  - Tons
  - Feet
  - Special instructions

- Schedules
  - Departure
  - Arrival
  - Protected times
Outputs

• Graphical Outputs
  – Time-distance graphs
  – Timetables
  – Train Performance Calculator (TPC)
  – Animations

• Textual Outputs
  – Reports for each train
  – Detailed delay Information
Research Methodology

- Create generic route to represent a conventional subdivision
- Conduct scenarios with different train types and dispatching sequences
- Quantify the results to evaluate the impact of heterogeneity
Representative Route

• Single Track
• 124 miles
• 10 miles between sidings
• 2.5 miles signal spacing
• 3-aspect signaling
• 0% grade and curvature
Trains Used in Analysis

**Intermodal**
- 75 cars
- 5,250’
- 6,750 tons
- 3 SD70 4,300 HP Locomotives
- 1.91 HP/Trailing Ton
- Max Speed: 70 mph

**Unit Coal**
- 90 cars
- 4,950’
- 12,870 tons
- 3 SD70 4,300 HP Locomotives
- 1.00 HP/Trailing Ton
- Max Speed: 50 mph
Trains Used in Analysis

**Manifest**
- 70 cars
- 4,550’
- 7,700 tons
- 2 SD70 4,300 HP Locomotives
- 1.12 HP/Trailing Ton
- Max Speed: 60 mph

**Passenger**
- 20 coaches
- 1,500’
- 835 tons
- 1 P42-DC 4,250 HP Locomotive
- 5.09 HP/Trailing Ton
- Max Speed: 79 mph
Braking Distances

- Passenger
- Intermodal
- Manifest
- Unit Coal
- Coal

Distance (ft)

Speed (mph)

- Manifest
- Intermodal
- Unit Coal
- Passenger
- Coal
Characteristics of Randomness

- Departure times evenly distributed randomly ± 5 minutes
- Resulting delays follow normal distribution
- Verified under Kolmogorov-Smirnov test
Freight Heterogeneity Study

- 3 freight-train types
  - Intermodal
  - Manifest
  - Unit Coal
- Evenly spaced over 24 hours
- Identical schedule in each direction
Heterogeneity Scenarios

- Parameters Tested
  - Train Combination
    - Pairwise combinations of train types
  - Volume
    - 28, 34, 40 and 46 trains per day
  - Different levels of heterogeneity
    - Heterogeneity corresponds to ratio of each train type

10%  33%  50%  66%  90%
CN Parametric Model Results

Parametric (CN)

- Coal with Intermodal
- Coal with Manifest
- Manifest with Intermodal

Delay (min)

Percent of Added Trains

0 10 20 30 40 50 60 70 80 90 100

0 10 20 30 40 50 60 70 80 90 100
RTC Simulation Results

Simulation (RTC)

Delay (min)

Percent of Added Trains

- Coal with Intermodal
- Coal with Manifest
- Manifest with Intermodal

Coal with Intermodal
Coal with Manifest
Manifest with Intermodal
Use of Parametric Model for Heterogeneity Analysis

- Parametric model excels at providing a fast way to estimate the delay and the resulting capacity on a line with limited heterogeneity
  - Good for network-level analysis
  - Average speed calculated based on minimum run times of different train types
    - Does not account for meets or passes
    - Does not account for fine-grained characteristics of train performance
- Study objective is to assess effect of detailed train performance characteristics
  - Requires use of simulation model
Effect of Heterogeneity and Density on Delay

- 46 Trains per Day
- 40 Trains per Day
- 34 Trains Per Day
- 28 Trains per Day

Percent Coal Trains vs. Delay per 100 Train Miles (min)
Increase in Delay due to Volume

The graph shows the increase in delay (in minutes) as a function of the volume (in trains per day). There is a significant increase in delay as the volume increases from 28 trains per day to 46 trains per day.
Increase in Delay due to Percentage of Heterogeneity

- 1% - 32%
- 33% - 66%
- 67% - 99%

Percentage of Heterogeneity

Delay (min)

- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350
Increase in Delay due to Train Type Combinations

- Intermodal and Unit Coal: Delay (min) = 250
- Intermodal and Manifest: Delay (min) = 100
- Manifest and Unit Coal: Delay (min) = 100
Specific Factors Affecting Heterogeneity

- Intermodal and Coal trains have highest delays, but why?
  - Priority?
  - Physical train characteristics (HPT, tonnage)?
  - Speed Difference?

- Analyzed at mix of Intermodal and Unit-Coal at 46 trains per day
Train Characteristics vs. Priority

[Graph showing the relationship between the percentage of coal trains and delay per 100 train miles for different train priority levels.]

- Intermodal Higher Priority
- Coal Higher Priority
- Same Priority
Delay of Specific Train Types When Priorities are the Same

- Minimal Difference in Delay
- Average Delay of 37 Minutes
Delay of Specific Train Types When Intermodal Has Higher Priority

- 40-Minute Increase in Average Delay for Unit Coal
- 1-Minute Decrease in Average Delay for Intermodal
- Average Delay of 51 Minutes
Delay of Specific Train Types When Unit Coal Has Higher Priority

- 34-Minute Increase in Average Delay for Intermodal
- 6-Minute Decrease in Average Delay for Unit Coal
- Average Delay of 46 Minutes
Impacts due to Freight Heterogeneity

- Two ways to consider impacts:
  - **Train Starts**
    - Compare delays to delay-volume graph in homogeneous conditions
  - **Delay Cost**
    - Cost incurred by the railroad due to delay

- Results specific for this model but provides idea of magnitude
Train Starts Lost due to Heterogeneity

- From delay-volume curve at 46 intermodal trains per day the delay is 35 minutes.
- A traffic mix of 50% intermodal and 50% unit coal increases delay 100%, up to 70 minutes.
- If the traffic was homogenous the lost capacity is:
  - 24 intermodal trains
  - 16 unit coal trains
Delay Cost due to Heterogeneity

- Four components of cost
  - Unproductive locomotive cost
  - Idling fuel cost
  - Car/equipment cost
  - Crew cost
- Estimated at $261 per train-hour
- 46 Trains per day (50% Intermodal, 50% Unit Coal)
  Total annual cost = $1.8 million
Passenger Heterogeneity Study

- Passenger trains added to base levels of freight
  - 80% manifest
  - 20% intermodal
- Pairs of passenger added
  - Evenly spaced
  - Up to 4 in each direction (8 total)
Delay to Freight Trains

Number of Trains

Freight Delay per 100 Train Miles (min)

32 Freight Trains/Day
36 Freight Trains/Day
40 Freight Trains/Day
44 Freight Trains/Day
Delay to Passenger Trains

- 32 Freight Trains/Day
- 36 Freight Trains/Day
- 40 Freight Trains/Day
- 44 Freight Trains/Day

Passenger Delay per 100 Train Miles (min)

Total Number of Trains

- +2
- +4
- +6
- +8
Conclusion

• Costs of heterogeneity are significant

• Impacts of freight heterogeneity dependent on level of:
  – Heterogeneity
  – Volume of traffic
  – Priority

• Impact of passenger traffic causes greater impact than corresponding number of freight trains
Future Work

- Perform economic analysis of possible mitigation techniques
- Perform heterogeneity study with double track model
- Analyze impacts of commuter rail
Acknowledgments

• Support and assistance from Eric Wilson of Berkeley Simulation Software and Harald Krueger of CN

• Support from CN Graduate Research Fellowship in Railroad Engineering

• Dr. Chris Barkan and Dr. Yung-Cheng Lai
Speed Ratio vs. Speed Difference

- Four scenarios simulated
  - Two with a *Speed Difference* of 10 mph
  - Two with the same *Speed Ratio* as the two with the same speed difference
- Compared correlation coefficients of the train delays

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