William W. Hay Railroad Engineering Seminar

“Measuring Performance of the National Rail Network”

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Association of American Railroads
University of Illinois at Urbana-Champaign
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Measuring Performance of the National Rail Network

William W. Hay Railroad Engineering Seminar Series
University of Illinois
November 1, 2013
The Project

- Designed to look at the performance of the national rail network using publically available data.
- Sponsored by TTCI
- Examine the period 1987 – 2009
- Work performed April – June 2011
Why 1987 – 2009?

- Period of prolonged stress and network reconfiguration.
- Period of rapid growth in freight movements (Figures 1 & 2):
  - 1991 – 2004 for manifest
  - 1987 – 2006 for intermodal
  - 1987 – 2008 for bulk
- Period of refocus of business portfolio toward intermodal and bulk.
- Period of the most significant rail restructuring of the last century.
- Period with reasonably consistent data available.
Figure 1 - Estimated Units Originated Annually by Service Type

Figure 2 - Estimated Revenue Tons Originated Annually by Service Type
Scope of Analysis

- Analysis performed at the national level.
- Makes no attempt to deal with significant issues in terms of individual rail properties.
What Data Was Used?

Two primary sources:

- Annual report R-1 of the Class I railroads to the STB.
- Quarterly commodity statistics reported to the STB by the Class I railroads
- Discontinuities or conflicts in both sources resolved where necessary.
Why Not Use the Weekly AAR Service Metrics for Analysis?

- Initiated in 1999 after several disruptive service episodes.
- Designed to provide customers current information, not important, long-term operational attributes or trends.
- Specifications and individual data elements changed over period of collection based on customer requests.
- Not fully comparable across railroads.
Hypothesis

- The most probable factor in creating the stress to the rail network was growth in traffic.
- The most important factor in resolving the disruptions appears to have been the industry restructuring particularly the industry consolidations.
- The data will reflect the network disruptions and will provide the opportunity to better understand the value to the rail industry of a free flowing network.
Restructuring the Network

- Since 1987 restructuring has created seven robust Class I railroads.
- Carriers have faced the necessity of reshaping their physical plant, equipment and management systems.
- They have had the opportunity to take advantage of economies of density and scale not available to earlier generations.
- The disruptions during this period have provided data that would not otherwise be available.
Rail Network Performance

Based on 2 factors:

- Availability of human and physical assets
- Process and plan through which the assets are deployed and managed
Two Basic Definitions

- Network velocity (Figure 3) – Basic measure of network capacity and fluidity. Time component based on average time for train to operate from origin to destination including all necessary stops, regardless of cause. Largely determined by whether a train is, or is not, moving – not by how fast it may travel when moving. Measured in miles-per-hour.

- Track speed – The speed reflecting the minimum time in which a train can transit a track segment.
Network velocity declined 5.32 mph between 1992 and 2006.
Potential Causes of Disruptive Congestion to be Examined

- Average track speed.
- Slow orders due to maintenance or construction restrictions.
- Impact of increasing train density.
- Terminal fluidity and operating capacity.

Most analysis in the remainder of this presentation will focus on the period 1992 – 2006 when network velocity was generally in serious decline.
Average Track Speed

- In 1992 = 41.4 mph.
- In 2006 = 44.9 mph => 8.5% increase in track speed during this period.
- Mainline track basically flat during entire period.
- Lightly used branch lines more volatile but trended slightly downward.
- Unlikely source of additional network delay and disruption.
Slow Orders From Maintenance or Construction

- 1992 = 1575 miles on a 91,752 mile mainline network (1.7%).
- 2006 = 4499 miles on a 99,057 mile mainline network (4.5%)
- Sufficient Impact to warrant further investigation (Figure 5 and Table 1).
Slow Order Impact Analysis

- Estimate impact of change in average trip times due to slow orders in 1992 versus 2006.

- Data used:
  - Average track speed (Figure 4),
  - Distance traveled by average train (Figure 6),
  - Average train length (Figure 7).

- Computational process and results shown in Table 1.
  - Average track speed with slow orders in 1992 = 40.1 mph.
  - Average track speed with slow orders in 2006 = 39.81 mph.
  - Net reduction in average speed = 0.29 mph.
Table 1 – Increase in Trip Time (Reduction or Increase in Average Trip Speed) Due to Slow Orders – 1992 versus 2006

<table>
<thead>
<tr>
<th></th>
<th>1992</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track Speed - Miles per Hour</td>
<td>41.4</td>
<td>44.9</td>
</tr>
<tr>
<td>Unobstructed Trip Time – Hours</td>
<td>5.15</td>
<td>5.54</td>
</tr>
<tr>
<td>Train Length (cars, miles)</td>
<td>0.73</td>
<td>0.75</td>
</tr>
<tr>
<td>Trip Length per Train Start - Miles</td>
<td>213.1</td>
<td>248.8</td>
</tr>
<tr>
<td>Distance Between Slow Orders – Miles</td>
<td>57.16</td>
<td>17.12</td>
</tr>
<tr>
<td>Slow Orders per Trip – Miles</td>
<td>3.73</td>
<td>14.53</td>
</tr>
<tr>
<td>Slow Order Miles Operated - (slow order miles) x (train length +1)</td>
<td>6.45</td>
<td>25.43</td>
</tr>
<tr>
<td>Miles at 20 Miles per Hour</td>
<td>6.45</td>
<td>25.43</td>
</tr>
<tr>
<td>Hours at 20 Miles per Hour</td>
<td>0.32</td>
<td>1.27</td>
</tr>
<tr>
<td>Miles at Track Speed</td>
<td>206.7</td>
<td>223.4</td>
</tr>
<tr>
<td>Hours at Track Speed</td>
<td>4.99</td>
<td>4.98</td>
</tr>
<tr>
<td>Total Transit Hours</td>
<td>5.31</td>
<td>6.25</td>
</tr>
<tr>
<td>Average Trip Speed</td>
<td>40.1</td>
<td>39.81</td>
</tr>
<tr>
<td>Change in Trip Speed From Slow Orders - Miles per Hour</td>
<td>-</td>
<td>-0.29</td>
</tr>
</tbody>
</table>
Implications of Slow Order Analysis

- Clearly a source of disruption but cannot account for the network velocity drop experienced between 1992 and 2006.

- Offset by the increase in average track speed during the same period.
Increasing Train Density

- 2006 – 70,212 miles with density > 20 million GTM/mile.
- $67.5 billion in infrastructure capital during period.
- 1830 additional 2\textsuperscript{nd} and 3\textsuperscript{rd} main track miles constructed during period.
Train Density Impact Analysis

- Estimate impact of change in average trip times due to train density in 1992 versus 2006.

- Data used:
  - Average train starts per day (Figure 10),
  - Total line of road track miles (Figure 11),
  - Plus data from slow order impact computation.

- Computational process and results shown in Table 2.
  - Average track speed with 1992 density = 38.33 mph.
  - Average track speed with slow orders in 2006 = 39.68 mph.
  - Net *increase* in average speed = 1.35 mph.
Average daily trains operated increased from 5003 in 1992 to 6197 in 2006.
### Table 2 - Increase in Trip Time (Reduction or Increase in Average Trip Speed) Due to Density – 1992 versus 2006

<table>
<thead>
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</tr>
<tr>
<td>Trip Length per Train Start – Miles</td>
<td>213.1</td>
<td>248.8</td>
</tr>
<tr>
<td>Daily Average Train Starts</td>
<td>5003</td>
<td>6197</td>
</tr>
<tr>
<td>Line-of-Road Miles</td>
<td>141,419</td>
<td>122,499</td>
</tr>
<tr>
<td>Average Daily Train Density – Trains per Mile</td>
<td>0.03538</td>
<td>0.05058</td>
</tr>
<tr>
<td>Train Starts per Day per Trip Length Segment</td>
<td>7.54</td>
<td>12.58</td>
</tr>
<tr>
<td>Train Starts During Average Trip</td>
<td>1.62</td>
<td>2.92</td>
</tr>
<tr>
<td>Average Train Meets per Trip</td>
<td>0.81</td>
<td>1.46</td>
</tr>
<tr>
<td>Average Delay – Hours</td>
<td>0.41</td>
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<td>Average Trip Speed – Miles per Hour</td>
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<tr>
<td>Change in Trip Speed From Density</td>
<td></td>
<td>+1.35</td>
</tr>
</tbody>
</table>
Implications of Train Density Analysis

- Potential source of disruption but clearly cannot account for the network velocity drop experienced between 1992 and 2006.

- Appears that the capital spending on new track capacity more than offset the increase in density during this time period.
Impact of Considering Slow Orders Plus Density

- Adding the impact of slow orders and density together substantially changes the results.

- Data used:
  - All data in both prior analyses.

- Results:
  - Average track speed with 1992 density = 37.26 mph.
  - Average track speed with slow orders in 2006 = 35.85 mph.
  - Net decrease in average speed = 1.41 mph but still only 27% of the total reduction in network velocity.
Figure 19 - Rail Capital Expenditures

- Roadway and Structure Capital
- Equipment Capital
However, What is Impact Without Capacity Investments

- 2006 traffic levels with the 1992 network would appear to have a very significant impact on network velocity.

- Data used:
  - All data in both prior analyses except average track speed held at 41.4 mph.

- Results:
  - Average track speed with 1992 density = 37.26 mph.
  - Average track speed with 2006 slow orders and density = 29.67 mph.
  - Net *decrease* in average speed = 7.59 mph or 2.27 mph beyond the total actual reduction in network velocity.
If Line-of-Road Does Not Explain Results – What Does?

- What drives train speeds to zero for extended periods?
- Cannot be done using line-of-road factors only.
  - Maximum impact from line-of-road should be approximately one-half of track speed.
  - Can continue as long as terminals can accept and dispatch trains without delay.
Terminals – Can’t Separate From Network Velocity

- Usually when a train does not advance over the road it is because it has nowhere to advance.
- On line-of-road this is manifested in blocked sidings.
- The most frequent cause of blocked sidings is the inability to advance trains into a terminal causing the sidings to be used as storage locations.
- Terminal blockage suggests the terminal is unable to process or store the number of cars required to remain fluid.
- 1992 – 2006 industry trends suggest this might be the case and should be explored.
1992 – 2006 Trends Effecting Terminal Fluidity

- Total number of freight cars occupying the network (increasing – Figure 13).
- Total number of carloads originating each year (increasing – Figure 14).
- Total loaded cars moved in non-unit trains – those most likely to demand substantial terminal resources (increasing – Figure 14).
- Miles of yard and switching track available to support sorting and car storage demands of the network (decreasing – Figure 15).
Freight Cars Occupying the Network

- In 1992, about 12,050 miles of freight cars occupied the US network.
- In 2006, the number of miles of freight cars had increased to 14,200 miles.
- The additional cars required about 2,150 miles of additional track simply to store the growth in the freight car fleet.
- Most of this “storage” had to occur on yard trackage.
Total and Non-Unit Train Carloads Originated

- Total carloads originated grew steadily from 1992 – 2006 other than 2001 (a mild recession year).
- Non-unit train carloads originated grew steadily from 1993 – 2005 with the exception of 1999.
Figure 13 - Active Freight Cars, U.S. Railroads

Figure 14 - Total and Non-Unit Train Carloads Originated

Figure 15 - Yard Switching Track

Figure 16 - Trends of Factors Consuming Yard Capacity
Meanwhile – Yard Switching Track Declined Steadily

- In 1992 there were 32,250 miles of yard track available for switching railcars.
- By 2006 this had declined to 26,250 miles, a 6000 mile decline.
- The availability of track for switching cars in yards was further influenced by the additional 2150 miles of cars in service on the network by 2006.
How These Trends Look Together

- Figure 16 brings all of the relevant trends together by indexing their values.

- Summary – More cars to switch, more cars to store, fewer miles of track to accomplish either.

- However, a more important number is the number of switching events that yards needed to deal with during this time period.
Handling Events

- Has two components for each carload:
  - Inter-train events, and,
  - Origin and destination events.

- Must be adjusted to reflect an appropriate number of empty cars based on loaded versus empty car-mile data.

- Method almost certainly understates total number of events since it does not account for reciprocal switch or equipment service events.

- See Figure 17 for results.
Figure 17 - Yard Switch Events per Loaded Non-Unit Train Car Originated

Yard Switching Events per Car

- Total Yard Switch Events /Loaded Car

What Happened in the Yards?

- Events declined from 10.0 per car down to 9.2 per loaded car from 1987 - 1991.
- From 1992 forward began to increase with growing traffic to 12 per car in 1996.
- Almost continuous event reductions through 2005 and has held steady since that time at about 8.5 per loaded car.
What Happened in the Yards?

- Strongly suggests that operational redesigning of the new, larger networks utilizing newly available levels of density and geographic scope was taking place.

- Factors included:
  - Fewer required interchanges,
  - Greater origin-destination volumes
  - Ability to operate longer distances without requiring switching of cars.
  - Operation of interline trains that eliminated interchange where it remained necessary.
Impact on Network Velocity

- By computing switching events per mile of available yard track, including both the raw value and the value adjusted for the changes in additional freight cars in the system, and converting both these values as well as network velocity to index values allows a look at the relationship between the two.

- The correlation coefficient for the relationship between the adjusted track available and network velocity is -0.865 (Figure 18).
Figure 18 - Impact of Switching Requirements on Network Velocity

Correlation Coefficient = -0.831

Correlation Coefficient = -0.865
Implications

- Improvements in terminal performance and the reduction in switching have not come from an increase in the size of terminals.

- Generalized terminal growth would probably have been counterproductive.
  - Would have diverted resources away from line-of-road capital.
  - Would have diverted resources away from new terminal investments required to reconfigure toward growing business lines.
  - Would have increased maintenance cost.
  - Would quickly have become obsolete with the results obtained from redesigning the network operating plan.
Implications

- The huge role played by operations planning in management of large, complex rail networks. Over sixty-five million annual yard work events were eliminated from the system between 1997 and 2005.

- The critical relationship between terminal fluidity and capacity and performance of the network, including the line-of-road component.

- Any policy which increases the requirements for switching is almost certain to have a negative impact on the performance of the network both for customers and for the railroad.
Conclusions

• Important line-of-road factors related to congestion include the density of traffic operating on the network and the impact of slow orders. However,

• Line-of-road factors alone cannot explain the impact of congestion on the rail network between 1992 and 2006.

• Data indicate that, in the absence of serious line-of-road congestion, the best indicator of network velocity is the number of switching events per mile of yard track available to perform those events.
Conclusions

- Solutions to yard constraints do not necessarily involve the construction of additional yard track. Operations planning and blocking strategies are critical to relief of yard congestion.

- It appears that investment in line-of-road capacity was sufficient between 1992 and 2006 to keep up with growing business demands and greater line utilization densities.

- The consolidations of the mid and late 1990s uniquely positioned the rail industry to deal with terminal volumes and congestion through plan redesign rather than capital expenditure.