Network Effects and Cost of Railroad Crosstie Maintenance and Replacement

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RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
Objectives

• Develop a methodology for comparing the economics of using timber or concrete crossties

• Look at higher level and long term costs to get a complete picture of the potential costs and benefits of each crosstie type
Maintenance costs and benefits

• Costs
  o Consist of:
    • Direct costs to performing the maintenance
    • Indirect costs to delayed trains
  o Depend on:
    • Labor
    • Equipment
    • Materials
    • Train delay
    • Network effects
    • Maintenance frequency

• Benefits
  o Consist of:
    • Reduction in derailment risk
    • Reduction in likelihood of slow orders
    • Decreased track degradation rate
  o Depend on:
    • Maintenance efficiency
    • Track degradation rates
    • Derailment costs
    • Track class
• Crosstie life distribution was based on Forest Service Product Curve (FSPC)\(^1\) with approximately 30-year tie life\(^2\)
• Model identified years when more than 800 ties needed to be replaced based on the number of remaining ties from each previous tie replacement for 20-inch tie spacing
• Approximately 800-900 ties replaced every 9-10 years
• Assume 850 ties are replaced every 9 years
• For concrete ties, assume out-of-face replacement every 45 years
**Estimated direct costs**

<table>
<thead>
<tr>
<th>Timber tie track renewal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$95</td>
<td>Cost per tie installed²</td>
</tr>
<tr>
<td>850</td>
<td>Ties replaced per mile</td>
</tr>
<tr>
<td>$80,750</td>
<td>Cost per mile per cycle</td>
</tr>
</tbody>
</table>

*Assuming 24” tie spacing

<table>
<thead>
<tr>
<th>Concrete tie track renewal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$200</td>
<td>Cost per tie installed²</td>
</tr>
<tr>
<td>2,640</td>
<td>Ties replaced per mile*</td>
</tr>
<tr>
<td>$528,000</td>
<td>Cost per mile per cycle</td>
</tr>
</tbody>
</table>

*Assuming 24” tie spacing
Hourly delay cost components

- **Crew** ($79.81)$^3$
  - Crew members per train
  - Wage rate
- **Cars** ($62.16)$^3$
  - Car types
  - Cars per train
  - Contractual car hire rate
- **Lading** ($623.65)$^3$
  - Revenue per train
  - Cycle time
  - Return ratio
  - Car availability
- **Locomotives** ($73.81)$^3$
  - Locomotives per train
  - Value of locomotive
- **Fuel** ($0, $59, or $518)$^4,^5$
  - Locomotives per train
  - Fuel cost
  - Fuel efficiency
  - Type of disruption
  - Length of disruption
  - Length of reroute
- **Total**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Cost ($/train-hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopped</td>
<td>$839</td>
</tr>
<tr>
<td>Idle</td>
<td>$898</td>
</tr>
<tr>
<td>Running</td>
<td>$1,357</td>
</tr>
</tbody>
</table>

Costs are per train-hour and based on the nation-wide average for train composition and using a 4300 HP mainline locomotive.
Network effects

- Delay will propagate through the network as trains are rerouted resulting in increased congestion.

- Some delayed trains will result in connecting trains being delayed or specific cuts of cars missing their connection.

- Delayed trains may result in crews running out of hours before the planned crew change location.

- Delay cost can be found on a per-train basis, then applied to all trains affected by the service disruption.
  - Disruption can be modeled using a rail traffic simulator.
  - Additional train-hours of delay and fuel use can be determined.
  - Can use delay-volume curves.
Maintenance situations

- Infrastructure type
  - Single track
  - Multiple track

- Network location
  - Alternate routes available
  - No possibility for rerouting

- Types of disruptions
  - Planned
  - Unplanned
    - Service failure
    - Slow orders
Example Network

- Single track with a portion of double track and alternate route
- Single track with alternate route
- Double track with alternate route
- Double track with no route alternatives
- Single track with no route alternatives
• Benefits are primarily defined as the reduction in risk
  o Risk = probability x consequence
• Probability of a derailment is determined by the rate of derailments of a certain type
• The consequence is based on historical costs
• Indirect benefits may result from a reduction in maintenance associated with improved track condition
  o These benefits can be considered when determining the life cycle costs of a particular maintenance strategy
### Derailment risk

<table>
<thead>
<tr>
<th></th>
<th>Concrete</th>
<th>Timber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic density (MGT)</td>
<td>76.2*</td>
<td>30.3*</td>
</tr>
<tr>
<td>Assumed miles of track</td>
<td>3,165^1</td>
<td>27,806^1</td>
</tr>
<tr>
<td>Percent of accidents</td>
<td>17%*</td>
<td>83%*</td>
</tr>
<tr>
<td>Accident rate per billion gross ton-miles</td>
<td>0.152</td>
<td>0.208</td>
</tr>
<tr>
<td>Average accident cost</td>
<td>$354,4517</td>
<td>$354,4517</td>
</tr>
<tr>
<td>Accident cost per billion gross ton-miles</td>
<td>$54,014</td>
<td>$73,727</td>
</tr>
</tbody>
</table>

- Delay costs will vary based on the operating conditions.

*based on data from a Class I railroad
^1assuming 6.5%^8 of all crossties are concrete
Slow order rates

- FRA Track safety standards require a minimum number of ties per 39 feet\(^9\)
- Slow order probability for an average 39-foot track section was determined using the FSPC\(^1\)
- Number of slow orders over the entire line was approximated using the 39-foot slow order probability as an average for each line
- This number was calculated for each year between tie renewals and adjusted to assume that the ties replaced in the previous year will not result in a slow order the next year
Slow order risk

- The slow order rate per 39 feet is applied to the entire line to determine a slow order rate per year for each route.
- The direct cost is calculated using the cost to install a tie.
- Delay costs are determined by multiplying the number of trains affected, the additional time required to traverse the slow order, and the delay cost.
- Assumptions:
  - 2 ties are replaced per slow order.
  - Slow order is in place for 5 hours.
  - Slow orders are imposed on tenth of a mile sections.
  - Spot tie replacements don’t disrupt traffic.
Other track maintenance

- Concrete ties are reported to hold line and surface better, but no published research was found to support this.
- Previous AAR research found that tie quality was not found to significantly impact rail maintenance\(^\text{10}\).
- Higher bad tie counts were found to impact the cost effectiveness of track surfacing\(^\text{10}\).

<table>
<thead>
<tr>
<th></th>
<th>Timber</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfacing cycle (years)</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Surfacing cost per mile</td>
<td>$18,031(^\text{11})*</td>
<td>$6,341(^\text{11})*</td>
</tr>
</tbody>
</table>

* Adjusted to 2012 dollars
Case study

- Class 4 track
- Moderate climate
- Range of curves
- 240 Mile legs
- 10 mile siding/crossover spacing
- 2 mile sidings
- 6.5 hour work windows
- 15 minute start-up and break-down time
- 6,723 tons per train

Maintenance Planning - 15
NPV – Renewal costs

- Analysis was performed over 45 years
- 11% interest rate
NPV – Derailment costs

- Assuming 24 hour track outage after a derailment
- Analysis was performed over 45 years
- 11% interest rate
NPV – Slow order cost

- Assume concrete ties do not degrade enough to be the cause of a slow order
- Replace an average of two ties per slow order
NPV – Surfacing costs

- Analysis was performed over 45 years
- 11% interest rate
Analysis was performed over 45 years
11% interest rate
NPV – Direct cost summary

- Analysis was performed over 45 years
- 11% interest rate
Future work

• Gather validation data
• Perform sensitivity analysis on the factors affecting life cycle costs to determine which need more detailed values
• Identify conditions where concrete ties are cost justified
Questions or comments?

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References

1. MacLean, J.D. 1957. *Percentage Renewals and Average Life of Railway Ties* No. 886, Forest Service Forest Products Laboratory. Madison, WI.


8. Uzarski, D.R. 2012. Learning Module 5 – Ties, lecture notes distributed in CEE 409 at the University of Illinois at Urbana-Champaign, Fall 2012.


Sogin delay calculations

- $D = (S_1 - S_2 \times x) e^{kV}$
  - $D =$ Train delay (minutes/train)
  - $S_1 =$ Single track delay constant (19.5206)
  - $S_2 =$ Delay mitigation constant (19.149)
  - $x =$ Double track percentage
  - $k =$ Congestion factor (0.0471)
  - $V =$ Traffic volume (trains/day)
Hypothesized relative costs

- Costs may vary based on the conditions where the maintenance is to be performed
- Unplanned disruptions will always result in higher costs including materials
- Infrastructure can range from single track to having two or more tracks
- Network location can range from no alternate routes to alternative routes of various levels of convenience to a parallel route

<table>
<thead>
<tr>
<th>Cost</th>
<th>Infrastructure</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single → Multiple</td>
<td>No alt → Parallel</td>
</tr>
<tr>
<td>Material</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>Equipment</td>
<td>Increasing</td>
<td>Decreasing</td>
</tr>
<tr>
<td>Labor</td>
<td>Increasing</td>
<td>Decreasing</td>
</tr>
<tr>
<td>Train delay</td>
<td>Decreasing</td>
<td>Decreasing</td>
</tr>
<tr>
<td>Network effects</td>
<td>Decreasing</td>
<td>Increasing</td>
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</tbody>
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