THE IMPLICATIONS OF HEAVY AXLE LOAD OPERATIONS FOR TRACK MAINTENANCE ON SHORT LINES

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ABSTRACT

North American freight railways have increased axle loads on high volume commodities such as grain, coal, and ore because of the significant savings in overall operating costs that result from heavier cars and corresponding higher axle loads. The resulting savings are in spite of increased maintenance of way and structures costs that result from the operation of the heavier cars and higher axle loads. Testing and subsequent experience has shown that well maintained main line track with heavy rail, sound ties, and good ballast sections can support these higher axle loads, though with an increase in the “annual” maintenance costs due to greater track component damage and shortened component lives.

However, short lines often operate track with light rail sections and marginal tie and ballast condition. The effect of these increased axle loads are not as well defined for this type of track and railway operation. Yet many short lines are facing the requirement to accept these heavier cars from their main line connecting partners. The implications of this to the short line operators can be potentially very significant.

This paper presents the results of two specific studies performed on two different short line (regional) railroads on the effect of heavy axle load cars on present and future maintenance of way costs. This includes the potential need to upgrade track components such as rail, as well as the anticipated increase in maintenance costs in all of the key track maintenance areas to include rail, ties, and ballast (surfacing). One of the two study railroads already permits HAL 286,000 lb. cars on one line, and is looking to permit these HAL cars on several other lines that it operates. The second short line does not currently allow HAL equipment. In both cases, this paper examines the start up, short term and long term implications of operating 286,000 lb. cars on these two short line railroads.
INTRODUCTION

Railways are coming under increasing pressure to reduce operating costs to permit them to compete more effectively and increase their level of profitability. In many cases, these pressures to reduce costs are occurring at the same time as the need for capacity grows, particularly in the case of high density main line corridors on US Class 1 railroads. One approach that has been able to address both of these areas of concern is the increasing of car capacity (and weight). By increasing the capacity of the freight cars, with little or no corresponding increase in the “tare” weight, it is possible to increase train capacity by 10 to 20%. In addition, the reduction in the number of cars needed to carry a fixed amount of commodity, results in a measurable decrease in the capital costs associated with car (and in many cases locomotive) acquisition, as well as reductions in operating and equipment maintenance costs, due to the reduced number of cars and trains.

Over the past 50+ years, North American freight cars (and freight trains) have been steadily growing heavier (1). For the most part this has been a response to competitive pressures, the inflexible nature of train crew costs, and increase in bulk commodity traffic such as grain, coal, ore, and aggregates. This has led to the recent introduction of 36 ton axle load cars (with a gross weight on rail of 286,000 lb.) for bulk commodity traffic. In addition, 39 ton axle loads have been used on a limited basis (e.g. intermodal equipment limits), with serious investigation ongoing into their broader introduction. Table 1 presents a summary of “heavy axle load” (HAL) car sizes and corresponding axle loads.

This trend to heavier cars has been accompanied by considerable research into the costs and benefits of larger cars and heavier trains. This includes both the issues of increasing car size, through the introduction of new equipment, and the issue of increasing the loading of existing
cars. Recent economic benefit studies have shown that significant operating savings exist for Class 1 railroads and shippers (2,3,4,5, and 6). This overall benefit is in spite of increases in track and structure maintenance costs.

However, this trend to heavier cars, particularly heavy axle load cars, has serious potential impact for short lines and regional railroads. This includes impact in the area of safety (and the potential for increasing number of derailments) as well as the impact of increased maintenance of way and structures costs, both operating and capital. This is of particular concern since many short lines have marginal track and bridge conditions which may result in a higher increase in maintenance (and capital upgrade) costs than that incurred by Class 1 railroads with well maintained right of ways.
Overview

From an engineering standpoint, there is no question that heavy axle loads shorten track component lives, increase the rate of degradation of the track structure, and increase the risk of derailments. Likewise, equipment maintenance costs, *per car*, may increase with increased car loading.

However, the operating savings that can be achieved by operating fewer but larger cars, offer several benefits, including:

- Need for fewer cars to transport the same volume of commodity
- Reduced equipment capital costs
- Possible reduction in overall car maintenance costs
- Need for fewer trains
- Possible reduction in locomotives required
- Improved net to tare ratio (ratio of goods carried to empty car weight- see *Table 2*)
- Reduced fuel consumption per net ton
- Reduced train weight per ton of goods carried
- Reduction in car and locomotive miles operated
- Fewer crew starts
Whether these operating savings do, in fact, off-set the increased track and equipment costs arising out of increasing axle loads, represents the key question in any evaluation on the overall benefits (and costs) of heavy axle load equipment. The answer to this question is both service-specific and route-specific because many of the key variables that can affect the outcome are both service and route specific. Thus, train weight and length are determined by grades and siding lengths (as applicable) and maximum feasible wheel loads by the load limit on bridges (which likewise enters into the economic analysis). Track maintenance costs are determined by the weight and type of rail, the age and condition of the ties, ballast quality, and the quantity of lubrication on curves. Conclusions reached regarding the optimum train weight, car weight, and train length for one route are not necessarily applicable to another.

While studies have shown a net benefit of the order of 3 to 8% of total cost for heavy axle loads on Class 1 railroads, short lines, with their more marginal track and structure conditions and their lower traffic densities, may not see this net benefit. In addition to increased maintenance costs, short lines and regional railroads may incur increased capital costs associated with upgrading of marginal bridges, replacement of lighter bolted rail with heavier CWR, and significant increase in ties inserted (beyond routine maintenance). There is also the potential for increase in derailments, again due to the higher level of loading associated with HAL equipment on marginal track. However, because of the significant benefits that accrue to Class 1 railroads, short lines may be required to accept these heavy axle load cars, even if overall economics of HAL equipment is not as favorable for the short lines themselves.

**Effects of Heavy Axle Load Traffic**

In the area of track and structures maintenance, to include both capitalized and expensed maintenance costs, heavy axle loads (HAL) most strongly effect MoW and Structures costs for:
• Rail and joints
• Ties and fastenings
• Ballast and surfacing
• Turnouts and special trackwork
• Bridges

While the effects of HAL traffic on Class 1 railroads has been well documented in earlier studies (2,3,4, and 5), the effects on short lines and regional railroads has not been as well addressed. However, the following effects of HAL traffic are expected to be most important on Short Lines and Regional Railways.

• Increase in surface degradation
  • Particularly at joints
• Increased degradation at turnouts.
  • Increased rate of rail degradation/failure
• Increase in surface spalling of rail.
  • Potential for increased rail defects
    • Joint defects
    • Fatigue defects.
• Increase in tie degradation
  • Particularly at joints
• Potential for capital costs for bridges (This paper will not address the bridge issue, however due to its potential importance it is specifically mentioned here.)
  • Particularly bridges marginal at 263,000 lb.
In order to examine these effects, in light of the earlier HAL research and studies, a series of heavy axle load studies were performed on several Midwestern US regional railroads. The specific railroad studies were as follows:

Railroad A: Regional railroad with approximately 143 miles of track maintained at FRA Class 3 with a 30 mph operating speed. Traffic was approximately 3 MGT per year and moved in predominantly 100 ton (263,000 lb.) cars. No HAL traffic was permitted. The traffic was primarily grain (53%) with significant amounts of coal (8%) and sugar (13%). The railroad’s terrain was flat and level, with grades generally less than 0.5% and curves less than 2°. The overall condition of track was very good for FRA Class 3, with predominantly 115 RE jointed rail and generally good tie and ballast condition.

Railroad B: Regional Railroad with approximately 600+ miles of track that is maintained at FRA Class 2 with a 25 mph operating speed or Class 1 with a 10 mph operating speed. The track is generally flat and level, with limited grades and curves generally less than 4 degrees. The railroad is a single track main line with limited number of sidings, primarily for grain shippers (elevators), etc. Traffic varies significantly by “subdivision” with one subdivision having 11 miles of 28 MGT annual tonnage with a significant percentage of 286,000 cars currently operating. The remaining subdivisions have traffic levels of the order of 1 to 2 MGT (2\textsuperscript{nd} and 3\textsuperscript{rd} Subdivision) and less than ½ MGT for the remainder of the system. No 286,000 lb. cars currently move on any of the other subdivisions. However they project approximately 20% of the traffic to be carried in 286,000 lb. cars within 5 years. The track condition varied significantly between subdivisions with the high density 1\textsuperscript{st} subdivision having good bolted 115 RE rail with good tie and ballast condition. The remaining subdivisions had track of varying
condition with rail sections as low as 72 lb. bolted rail (though the majority of the rail was in the 90 to 112 lb. range).

The analysis performed looked at the potential effect of operating Heavy Axle Load (HAL) cars, with a gross weight on rail of 286,000 lbs. This represents an increase in axle load from 32,875 (conventional 263,000 lb. cars) to 35,750 an increase of 8.7%. Note however, that the net of the heavy axle load cars improves, with the 286,000 lb. cars having a net of approximately 220,000 lb. as opposed to a net of approximately 200,000 lb. for conventional 263,000 lb. cars. This results in a reduction in the number of cars (and axles) needed to carry the same amount of commodity of approximately 8 to 10% (depending on specific car design). Thus, any damage assessment of the heavier axle load cars, must take into consideration the reduction in the number of axles needed to carry the same amount of commodity.

Using the damage exponent heavy axle load analysis approach developed in earlier heavy axle load studies (2,3,5), the damage effect of the heavy axle load cars was examined on a component by component basis. This damage exponent analysis approach uses the damage factor equation:

\[
\text{Damage Factor (per component)} = \left( \frac{P}{P_0} \right)^n
\]

Where

\[
P = \text{new axle load (32.875 tons)}
\]

\[
P_0 = \text{old axle load (35.75 tons)}
\]

\[
n = \text{damage exponent}
\]

This damage factor equation determines the per axle damage effect. By adjusting this damage to account for the difference in net to tare ratios between 263,000 lb. and 286,000 lb. cars (and thus the different commodity capacity per car), the damage per MGT can be likewise
calculated. The individual damage exponents, by component and component failure mechanism, (since these factors vary for different failure mechanisms (2)) were determined for the study regional railroads and are presented in Table 3. Table 3 and Figure 1 also present the component based damage effects on a per axle and a per MGT basis. [Again note that the per MGT results have been adjusted to account for the reduced number of axles needed to carry the same level of commodity movement.]

These damage effects are then applied to the actual short line MoW budgets to determine the corresponding increase in MoW (in this case: rail, ties, ballast, and turnout) expenses. Note, these effects (and the costs to which they are applied) also take into account the need for upgrade in any components; e.g. the need for a better quality wood tie under joints for HAL operations.
In order to apply these factors and determine an increased MoW cost, the following analysis steps are necessary:

1. Define the distribution of current maintenance costs by component (rail, ties, ballast) and component damage mechanism (see Table 3).

2. For each component type, calculate a consolidated damage factor (and exponent) based on all failure mechanisms of that component.

3. Modify each consolidated component damage factor by additional external factors (e.g. in the case of the short line analyses performed here an additional jointed rail factor was applied in jointed rail territory to define the additional damage associated with jointed rail).

4. Account for the axle adjustment factor (i.e. the reduced number of axles required to carry the same amount of lading).

5. Apply the modified component damage factors to the percentage of traffic being increased to heavy axle loads.

6. Calculate a composite damage factor as a function of the individual component damage factors and traffics.

Applying this step by step analysis procedure to the study railroads, as illustrated in Tables 4 and 5, give the following results:
Railroad A:

Noting that the effect of HAL operations is dependent, in part, on the condition of the track structure, a brief overview of Railroad A’s track structure condition is as follows:

- Rail is predominantly 115 RE jointed rail with limited CWR.
  - Joints are in good condition, with very limited batter or flow
  - No evidence of significant fatigue defects observed
  - Lubrication by hi-rail mounted lubricator on track inspectors truck
- Ties are wood cross-ties with cut spikes and double shoulder tie plates
  - Mix of hardwood and industrial grade (softwood)
  - Tie life is quite good (40+ years)
  - Ties are largest single MoW cost area
  - Ties appear to fail primarily due to plate cutting and/or crushing under rail seats, particularly at joints.
- Ballast is good granite ballast obtained from on-line source
  - Ballast was observed to be generally clean and uniform (4 –5” depth)
- Overall, roadbed was on good, well defined embankment with good drainage.
  - However, limited mud spots were observed (often at crossings)
- Turnouts appeared to be in good overall condition.

Based on the track condition noted above, and noting that railroad A currently carries no HAL (286,000 lb. cars), then, noting the analysis presented in Table 4:

If all traffic is converted to HAL cars, i.e. 100% of all traffic currently carried is moved in HAL cars, the following track maintenance cost increases are expected:
Increase in rail and turnout maintenance costs (to include capital costs associated with rail and turnout replacement): 27.5%

Increase in tie costs: 12%

(Includes the cost of upgrading to better crossties in the vicinity of the rail joints)

Increase in surfacing costs: 23%

**Overall increase in maintenance costs associated with rails, ties, ballast, and turnouts:** 17%

Note, this does **not** include any costs that are independent of traffic, such as track inspection costs, weed spray, snow removal, signal maintenance, etc.

Noting that grain is the predominant traffic on this railroad (53% of total traffic), then if 50% of the grain traffic **only** is converted to HAL cars, i.e. 27% of all traffic currently carried is moved in HAL cars, the following cost increases are expected:

Increase in rail and turnout maintenance costs (to include capital costs associated with rail and turnout replacement): 7%

Increase in tie costs: 3%

Increase in surfacing costs: 6%

**Overall increase in maintenance costs associated with rails, ties, ballast, and turnouts:** 4.6%
Railroad B:

A brief overview of Railroad B’s track structure condition is as follows:

- Rail section varied significantly, including 132, 115, 112, 100, 90 and 85 lb. and limited amounts of 72 lb. rail.
- Rail condition varied significantly based on traffic density and type.
- On mainline, 115 RE bolted rail, had significant surface degradation to include rail head spalling, surface fatigue, and joint batter (under traffic that already included significant numbers of 286,000 lbs. cars).
- Failure in joint area observed on some lighter section rails.
- Lubrication was not observed, however rail wear, in general was not observed (or reported) to be a major problem.
- Need for rail grinding, particularly to clean up gage corner spalling.
- Major issue is whether the 72 lb. rail or joint bars can accommodate 286,000 lb. cars.
  - Observed joint bar failures may require upgraded bars which are available for this size of rail.
- Ties are wood cross-ties with cut spikes and double shoulder tie plates
  - Single shoulder tie plates on the lighter rail sections.
  - Hardwood 7x9” ties on main line and No. 4 7x8” ties everywhere else.
  - Ties appear to fail primarily due to plate cutting and/or crushing under the rail seats, particularly at joints.
- Ballast is a good granite ballast obtained from an on-line source
- Observed to be generally clean and uniform.
- Overall roadbed on good, well defined embankment with good drainage.
- Spots with poor drainage and limited mud spots were observed.

Based on the track condition above, noting the analysis presented in Table 5, then:

If all traffic is converted to HAL cars, i.e. 100% of all traffic currently carried is moved in HAL cars, the following cost increases are expected:

- Increase in rail and turnout maintenance costs (to include capital costs associated with rail and turnout replacement): 28%
- Increase in tie costs: 12%
- Increase in surfacing costs: 26%

**Overall increase in maintenance costs associated with rails, ties, ballast, and turnouts:** 23%

Note, this does not include any costs that are independent of traffic, such as track inspection costs, weed spray, snow removal, signal maintenance, etc.

However, current Railroad B traffic projection show that approximately 20% of the traffic will be moved in HAL equipment over the next five years. Thus, if 20% of the traffic only is converted to HAL cars, the following cost increases are expected:

- Increase in rail and turnout maintenance costs (to include capital costs associated with rail and turnout replacement): 6%
- Increase in tie costs: 2.5%
- Increase in surfacing costs: 5%

**Overall increase in maintenance costs associated with rails, ties, ballast, and turnouts:** 4.5%
Figures 2 and 3 show these increased maintenance of way costs for both railroads in the case of both 100% HAL traffic and partial HAL traffic.

Implications for Short Lines and Regional Railroads

Based on the results of the HAL studies noted above, it is expected that an increase in maintenance costs of the order of 5 to 23% can be expected to occur, with the advent of a significant amount of HAL (286,000 lb. car) traffic. The exact increase being dependent on the percentage of traffic moving in HAL cars.

However, the impact of HAL operations must be examined both from the point of view of initiation of operation, i.e. what must be done before the start of significant HAL traffic operations, as well as for ongoing maintenance activities.

In the case of initiation of HAL operations, several actions were identified on the two study lines as being required prior to the initiation of HAL (286,000 lb. car) operations. These included:

- Performance of a full system rail test program to include ultrasonic testing of all rails, joints, etc. with a state of the art commercial rail testing service. This is of particular importance on lines with lighter rail sections (100lb. and below) but should be performed for all line segments scheduled to see HAL operations.

- Performance of bridge rating of any bridge that potentially may have problems with HAL cars. This is to include any bridge for which there is uncertainty regarding its condition or strength.

- Performance of a detailed inspection of ties and fasteners, particularly in all curves, from the point of view of lateral track strength (resistance to rail overturning and gage widening). Special emphasis should be placed on curves with lighter rail sections.
and single shoulder tie plates. If locations are of questionable strength, consider testing with hi-rail track strength/track geometry test car such as currently commercially available. Sufficient ties/fasteners should be present to avoid gage widening under the operation of heavy axle load cars.

Detailed evaluation of all light rail sections, particularly jointed rail sections below 90 lb. rail. If the rail section has a history of defects, such as joint bar or joint area failures, under 100 Ton car operations (263,000 lb. cars), then the rail section and/or the joint bars currently should be reviewed for adequacy in carrying HAL traffic. Upgrade of joint bars, joint support (to include joint ties and ballast under joints) should be considered if there is such a history of failure under existing “conventional” equipment.

After the start of HAL operations, specific actions identified for ongoing maintenance included:

Performance of ongoing rail testing with the frequency of testing based on number of defects found and annual tonnage levels. This is necessary because of the increased risk of rail fatigue defects associated with the HAL traffic.

Ongoing monitoring of all rail sections, and in particular jointed light rail sections, such as below 90 lb. rail. If the rail section develops rail defects, to include joint bar or joint area failures as well as failures in the rail itself, then the rail section and/or the joint bars currently used should be reviewed for adequacy in carrying HAL traffic. Upgrade of joint bars, joint support (to include joint ties and ballast under joints) and rail section itself should be considered if there is an dramatic increase in failures under HAL equipment.

Improve quality of cross-ties being used under rail joints to minimum of 7”x9” hardwoods. Monitor tie condition under joints carefully.
Performance of periodic track geometry inspections of track. This is of particular importance in view of potential for joint and geometry degradation and should be performed as a minimum every second year. More frequent inspections may be necessary for higher density lines.

Use of high quality ballast for all surfacing and ballast applications. This is to reduce the rate of ballast degradation, fouling, and loss of surface, alignment and cross-level.

Performance of weld repair of rail joints with proper grinding and slotting of joints. This is of particular importance on jointed rail where HAL traffic will increase the rate of surface batter at the joints. Make sure that welding repair practice is appropriate for HAL operations, in light of the high stresses placed on the welds by the HAL equipment.

Inspection of switch points and frogs on an ongoing basis with a particular emphasis on surface condition (e.g. frog and switch point batter) geometry, and fracture of key components. Repair as necessary to include weld repair of batter. Make sure that welding repair practice is appropriate for HAL operations, in light of the high stresses placed on the welds by the HAL equipment.

Monitor rail head surface condition to include plastic flow, spalling, shelling, micro cracking, corrugations and other surface defects. Profile grind rail head as needed in order to maintain optimum wheel/rail contact and avoid development of defects from rail surface degradation.
Lubricate all curves greater than two degrees to reduce rail wear. The rate of rail wear will increase with HAL traffic and lubrication, using hi-rail or wayside applicators, can result in a significant extension of rail life.

CONCLUSIONS

The major US Railroads have been introducing and are moving towards heavier freight cars with increased axle loading. The motivation for this move to HAL equipment is a real overall reduction in total operating costs to these Class 1 railroads and large shippers. Because of this economic impact, short lines and regional railroads will be required to accept HAL equipment, even if they do not have the same overall net economic benefit.

This introduction of HAL cars will result in an increase in maintenance of way costs. The actual increase in costs will depend on how much HAL traffic is actually carried and can vary from 5 to 25 %+ of current MoW costs. In addition there is a potentially large need for capital improvements, particularly if rail needs to be replaced or upgraded (larger rails section, introduction of CWR, etc.) There is also a potentially large need for capital expenditures for bridge upgrading, if bridges are in poor or marginal condition and can not support the heavier 286,000 lb. equipment.

While the improved net to tare ratio of the heavier cars, with the corresponding savings in operating and capital costs, may offset most if not all of these increased MoW and Structures costs, it is still necessary for short line and regional railroads to be prepared for this increase in maintenance costs. Furthermore, many of the economic benefits will accrue over time, while several of the HAL related costs may be required up front, i.e. prior to the start of significant HAL operations. Thus short lines and regional railroads, most of whom do not have “deep
pockets”, must be prepared to address these issues and to insure that they are able to operate economically under their own conditions and circumstances.

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REFERENCES:


TABLE 1

Heavy Axle Load Limits

<table>
<thead>
<tr>
<th>Gross Weight on Rails (lb.)</th>
<th>Axle Load (Tons)</th>
<th>Status</th>
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<tbody>
<tr>
<td>263,000</td>
<td>33</td>
<td>Current AAR interchange limit</td>
</tr>
<tr>
<td>268,000</td>
<td>33.5</td>
<td>Overload</td>
</tr>
<tr>
<td>286,000</td>
<td>36</td>
<td>Current HAL weight for Class 1 RR</td>
</tr>
<tr>
<td>315,000</td>
<td>39</td>
<td>Future HAL Limit (currently under test)</td>
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</table>
TABLE 2
HAL Benefits

- Improved net/tare

<table>
<thead>
<tr>
<th>Gross Weight on Rails (lb.)</th>
<th>Net to Tare Ratio</th>
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</thead>
<tbody>
<tr>
<td>263,000</td>
<td>3.1</td>
</tr>
<tr>
<td>286,000</td>
<td>3.5</td>
</tr>
<tr>
<td>315,000</td>
<td>3.7</td>
</tr>
</tbody>
</table>

- Fewer cars needed
- Fewer car miles
- Fewer locomotives
- Fewer crew starts
- Less Fuel
### TABLE 3
Heavy Axle Load Damage Factors

<table>
<thead>
<tr>
<th>Component</th>
<th>Damage Exponent</th>
<th>Damage* (per axle)</th>
<th>Damage* (per MGT)</th>
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<tbody>
<tr>
<td>Rail Wear</td>
<td>1</td>
<td>+9%</td>
<td>0%</td>
</tr>
<tr>
<td>Rail Fatigue (internal)</td>
<td>3</td>
<td>+29%</td>
<td>+19%</td>
</tr>
<tr>
<td>Rail Fatigue (surface)</td>
<td>1.8</td>
<td>+16%</td>
<td>+7%</td>
</tr>
<tr>
<td>Rail Joints</td>
<td>3.33</td>
<td>+32%</td>
<td>+21%</td>
</tr>
<tr>
<td>Ties</td>
<td>1.5</td>
<td>+13%</td>
<td>+4%</td>
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<tr>
<td>Good Ballast</td>
<td>1</td>
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<td>0%</td>
</tr>
<tr>
<td>Poor Ballast</td>
<td>5.6</td>
<td>+60%</td>
<td>+47%</td>
</tr>
<tr>
<td>Turnouts</td>
<td>3</td>
<td>+29%</td>
<td>+19%</td>
</tr>
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*Based on 286,000 lb. car.
## TABLE 4
ANALYSIS OF RAILROAD A

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
<th>Axle Adj.</th>
<th>n</th>
<th>(P/P0)^n</th>
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</thead>
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<tr>
<td>Rail Wear</td>
<td>21.2%</td>
<td>0.92</td>
<td>1.00</td>
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<tr>
<td>Rail Fatigue (internal)</td>
<td>0.01%</td>
<td>0.92</td>
<td>3.00</td>
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<td>Rail Fatigue (surface)</td>
<td>7.0%</td>
<td>0.92</td>
<td>1.80</td>
<td>1.16</td>
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<tr>
<td>Rail Joints</td>
<td>39.4%</td>
<td>0.92</td>
<td>3.33</td>
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<tr>
<td>Turnouts</td>
<td>32.4%</td>
<td>0.92</td>
<td>3.00</td>
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<td></td>
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### Tie Damage Exponent

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<tr>
<td>Tie Damage Exponent</td>
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<tr>
<td>Wood</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ballast</td>
<td>95.00%</td>
<td>0.92</td>
<td>1</td>
<td>1.09</td>
</tr>
<tr>
<td>Poor Ballast</td>
<td>5.00%</td>
<td>0.92</td>
<td>5.6</td>
<td>1.60</td>
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<tr>
<td></td>
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### Ballast

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<th>95.00%</th>
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<th>1.09</th>
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<tr>
<td>Good Ballast</td>
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<td></td>
</tr>
<tr>
<td>Poor Ballast</td>
<td>5.00%</td>
<td>0.92</td>
<td>1.60</td>
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### Rail Tie (wood) Surfacing

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<thead>
<tr>
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<th>2.66</th>
<th>1.50</th>
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<tr>
<td>(P/P0)^n</td>
<td>1.25</td>
<td>1.13</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>1.15</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Jt Rail Factor

<table>
<thead>
<tr>
<th></th>
<th>1.11</th>
<th>1.08</th>
<th>1.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>mod P/P0^n</td>
<td>1.39</td>
<td>1.22</td>
<td>1.34</td>
</tr>
<tr>
<td></td>
<td>1.27</td>
<td>1.12</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Increase in costs as a function of percentage of HAL cars

<table>
<thead>
<tr>
<th></th>
<th>Rail</th>
<th>Tie (wood)</th>
<th>Surfacing</th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>all traffic</td>
<td>100%</td>
<td>27.5%</td>
<td>12.1%</td>
<td>23.1%</td>
</tr>
<tr>
<td>all grain</td>
<td>53%</td>
<td>14.6%</td>
<td>6.4%</td>
<td>12.3%</td>
</tr>
<tr>
<td>half grain</td>
<td>27%</td>
<td>7.3%</td>
<td>3.2%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

---

1 Internal fatigue is expected to increase as a function of rail section.
### TABLE 5
**ANALYSIS OF RAILROAD B**

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
<th>Axle Adj</th>
<th>n</th>
<th>((P/P0)^n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail Wear</td>
<td>16.0%</td>
<td>0.92</td>
<td>1.00</td>
<td>1.09</td>
</tr>
<tr>
<td>Rail Fatigue (internal)</td>
<td>0.0%</td>
<td>0.92</td>
<td>3.00</td>
<td>1.29</td>
</tr>
<tr>
<td>Rail Fatigue (surface)</td>
<td>12.0%</td>
<td>0.92</td>
<td>1.80</td>
<td>1.16</td>
</tr>
<tr>
<td>Rail Joints</td>
<td>43.0%</td>
<td>0.92</td>
<td>3.33</td>
<td>1.32</td>
</tr>
<tr>
<td>Turnouts</td>
<td>29.0%</td>
<td>0.92</td>
<td>3.00</td>
<td>1.29</td>
</tr>
<tr>
<td><strong>100.0%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tie Damage Exponent**

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
<th>Axle Adj</th>
<th>n</th>
<th>((P/P0)^n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>100%</td>
<td>0.92</td>
<td>1.5</td>
<td>1.13</td>
</tr>
<tr>
<td><strong>Composite n = 1.5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Ballast**

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
<th>Axle Adj</th>
<th>n</th>
<th>((P/P0)^n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Ballast</td>
<td>90.00%</td>
<td>0.92</td>
<td>1</td>
<td>1.09</td>
</tr>
<tr>
<td>Poor Ballast</td>
<td>10.00%</td>
<td>0.92</td>
<td>5.6</td>
<td>1.60</td>
</tr>
<tr>
<td><strong>100.0%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Composite n = 1.55**

<table>
<thead>
<tr>
<th></th>
<th>n= 2.71</th>
<th>Tie (wood)</th>
<th>Surfacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>((P/P0)^n)</td>
<td>1.25</td>
<td>1.13</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>1.15</td>
<td>1.04</td>
<td>1.05</td>
</tr>
</tbody>
</table>

**without axle load adjustment**

**with axle load adjustment**

<table>
<thead>
<tr>
<th></th>
<th>n= 2.71</th>
<th>Tie (wood)</th>
<th>Surfacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>((P/P0)^n)</td>
<td>1.25</td>
<td>1.13</td>
<td>1.14</td>
</tr>
<tr>
<td>Jt Rail Factor</td>
<td>1.11</td>
<td>1.08</td>
<td>1.20</td>
</tr>
<tr>
<td>mod (P/P0)^n</td>
<td>1.39</td>
<td>1.22</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>1.28</td>
<td>1.12</td>
<td>1.26</td>
</tr>
</tbody>
</table>

**without axle load adjustment**

**with axle load adjustment**

**Increase in costs as a function of percentage of HAL cars**

<table>
<thead>
<tr>
<th></th>
<th>% HAL cars</th>
<th>Rail</th>
<th>Tie (wood)</th>
<th>Surfacing</th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>all traffic</td>
<td>100%</td>
<td>28.0%</td>
<td>12.1%</td>
<td>26.0%</td>
<td>22.6%</td>
</tr>
<tr>
<td>projected</td>
<td>20%</td>
<td>5.6%</td>
<td>2.4%</td>
<td>5.2%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>

---

2 Internal fatigue is expected to increase as a function of rail section.
FIGURE 1: HAL Damage Increase

Component/Damage mechanism
FIGURE 2: Increase in MoW Costs
100% of Traffic Converted to HAL
FIGURE 3: Increase in MoW Costs
Limited % of Traffic Converted to HAL

Incresed MoW Costs

Rail/Turnout   Tie   Surfacing   Total
Component

RR A
RR B
## LIST OF TABLES and FIGURES

1. **TABLE 1** Heavy Axle Load Limits - ref on pg 3, para 2

2. **TABLE 2** HAL Benefits ref on pg 5, Overview, para 2, bullet 3

3. **TABLE 3** Heavy Axle Load Damage Factors - ref on pg 10, para 1 and pg 1, subpara #1

4. **TABLE 4** Analysis of Railroad A - ref on pg 11, last para and pg 12, para 3

5. **TABLE 5** Analysis of Railroad B - ref pg 11, last para and pg 15, 4<sup>th</sup> line

6. **FIGURE 1** HAL Damage Increase - ref on pg 10, para 1

7. **FIGURE 2** Increase in MoW Costs - ref on pg 16, para 1

8. **FIGURE 3** Increase in MoW Costs - ref on pg 16, para 1