TECHNOLOGY DIGEST
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The Economics of Removing Hollow Wheels from Service

by Kevin Sawley and Steve Clark

Summary

A study by Transportation Technology Center, Inc. (TTCI) indicates substantial system benefits and cost savings could be attained by removing hollow-worn wheels from North American service. The maximum predicted benefit is in the range of $17 to $57 million and occurs at a removal limit of 3 mm (0.12 inches). Future work will focus on preparing proposals for interchange rules for the removal of hollow-worn wheels and methods of identifying them.

Results from the study include:

- There is a positive benefit from removing hollow-worn wheels from service. The benefits predicted, using inflated wheelset maintenance costs to account for the fact that hollow-worn wheels do not always occur in pairs, are likely to be very conservative.
- Benefits are increased as the hollow-wear removal limit is reduced from 6 mm to 3 mm (0.24 inch to 0.12 inch).
- A removal limit of 2 mm (0.08 inch) gives a negative benefit. This reflects the larger numbers of moderately hollow wheels, and the relatively small increased benefits gained from removing 2-mm hollow wheels compared with 3-mm hollow wheels.
- The largest predicted benefits are related to decreased fuel use, and decreased rail wear leading to longer rail life.
- Benefits from reduced damage to special track work and lower derailment risk have not been calculated, but would further improve the case for removing hollow-worn wheels from service.

A survey of North American wheel profiles has shown that, although almost half the wheels in service have an approximately tapered profile, 6 percent have more than 3 mm (0.12 inch) hollow wear while 2 percent have more than 4 mm (0.16 inch) hollow wear .[1]

Hollow-worn wheels have been shown to increase rolling resistance, and hence fuel use and rail wear, and to raise lateral forces, which decreases life of wood-ties.[2] The false flanges of hollow-worn wheels also cause damage to special track work, currently repaired by welding, and cause surface deterioration of the low rail in curves, currently controlled by grinding.[3]

Suggested Distribution:
- ❑ Maintenance of Way
- ❑ Planning & Analysis
- ❑ Car Department
- ❑ Safety

Work performed by TTCI Transportation Technology Center, Inc.
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INTRODUCTION AND CONCLUSIONS

As part of the AAR's Strategic Research Initiative on Wheel/Rail Asset Life Extension, TTCI has examined the costs and benefits of removing hollow-worn wheels from service. A survey of wheel profiles indicates that many wheels in North America are worn to a hollow tread profile, illustrated in Exhibit 1 where the degree of hollow wear is shown as H.[1]

Hollow wear gives a "false flange" at the wheel end-of-tread area, reducing the ability of the wheelset to steer. This causes rolling resistance to rise (increasing fuel use and rail wear), and lateral forces to increase (leading to decreased wood-tie life).[2] These effects of hollow wheels on resistance and lateral force have been predicted using the NUCARS dynamics model. Track tests have verified model predictions. The false flange also increases stress in the rail, leading to surface deterioration of the low rail in curves, currently rectified by rail grinding, and significant damage to frogs and crossings, which are repaired by welding.[3] Removing hollow-worn wheels from service can reduce costs in these areas, yet gains need to be balanced against increased wheelset maintenance costs.

This digest describes the calculation of costs and benefits of removing hollow-worn wheels from service. For all but rail grinding, benefits and costs are calculated in terms of dollars per 1,000 net-ton miles for typical eastern and western coal-haul routes. North American system costs are found using estimates of east- and west-type traffic figures. Removal limits (H values, Exhibit 1) from 2 mm to 6 mm (0.08 to 0.24 inches) have been studied for 1-wear, 2-wear and multiwear wheels. Since many cars in North America use 1-wear wheels, only results for these wheels will be given. Results show that removing hollow-worn wheels from service can reduce overall system costs.

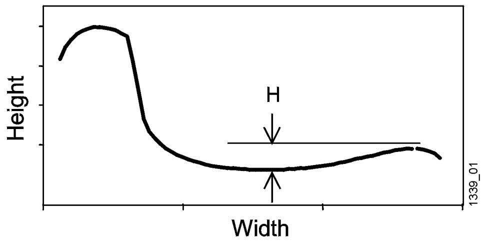

Exhibit 1. Illustration of Hollow-Worn Wheel

CALCULATION OF BENEFITS

Fuel and Rail-Wear Benefits

Since hollow-worn wheels raise rolling resistance, removing them from service reduces fuel use and rail wear. Fuel and wear reductions were studied using a train of 100-ton coal hoppers with standard trucks and different distributions of worn wheels. The base case assumed the wheel profile distribution given by the wheel survey.[1] In this case, the train had wheels varying from tapered to 6-mm hollow. Other cases assumed a similar distribution, but with the relevant hollow wheels removed. For example, for the 4-mm removal case, the train had no wheels with hollow wear 4 mm or greater. Thus for each case the train had a rolling resistance that could be found from verified dynamic model predictions. Note that it was assumed all wheels within a given car had the same profile. This is unlikely in service, but modeling of cars with differently hollowed wheels suggests that making this assumption is reasonable for calculating overall train resistance.

Fuel consumption due to rolling was assumed proportional to rolling resistance, and translated into work energy and then fuel energy. A combined diesel/electric efficiency of locomotive power of 28.5 percent was assumed, with a fuel energy density of 19,500 Btu/lb. and fuel costs of $0.60 per gallon.

The rail-benefit study assumed that wear was proportional to resistance, and used the same train with the same distributions of worn wheels as in the fuel study. For each removal case, the effect of reduced resistance on rail wear (and hence rail life) was found, assuming typical base-case rail lives, as shown in Exhibit 2. The wear study also assumed that all wheels within a given car were identical.

Rail Location	Rail Life (MGT)
Tangent	1,460
Curve - 1 degree	1,050
Curve - 2 degree	640
Curve - 3 degree	540
Curve - 4 degree	510
Curve - 5 degree	440
Curve - 6 degree	390
Curve - 7 degree	380

Exhibit 2. Assumed Average Rail Lives in North American Track

For each case, estimated eastern and western route rail lives were input to a rail capitalization model that calculated the life-cycle present value of rail costs for the idealized routes. These life-cycle cost estimates were based on the rail cost, rail lives, depreciation lives, and a discount rate of 10 percent. Present-value life-cycle costs were reduced to equivalent uniform annual costs using the standard discounting method for an annuity.

RAIL GRINDING BENEFITS

Removing hollow wheels will likely lead to lower rail-grinding costs, since hollow wheels are predicted to cause very high contact stresses on the top of the low rail in curves. A survey of North American railroads indicates that low rails are a main focus of grinding to remove surface defects (cracks and spalls), and to relieve the field side to prevent contact with the hollow wheel's false flange.[3] Calculation of benefits was based on estimated North American grinding costs of about $100 million per year, and maximum potential savings of $20 million per year. This assumes that 60 percent of grinding is focused on the low rail in curves, and that one-third of this can be saved. It was assumed that the damage caused by a given level of hollow wear was proportional to the stress produced at that level of wear multiplied by the probability that a given wheel had that level of wear. From tests, calculations, and theory, it was estimated that the critical contact stress for premium rail steel typically used in curves is 2,000 MPa (290 ksi). Above this figure damage becomes increasingly likely.

LONGER WOOD-TIE LIFE BENEFITS

Tie savings were calculated based on two sets of data: NUCARS lateral force predictions found for wheels from tapered to 6-mm hollow, and data relating average tie life to applied lateral force found from the TRACS model. The train used for the fuel and rail wear study was modeled on typical eastern and western routes with hardwood ties at 20-inch spacing. Speed was set at 30 mph, with an annual tonnage of 60 million gross tons (MGT). Installed tie cost was taken to be $43.

For each route and track curvature, the effect of hollow wear on tie life was calculated, based on the predicted lateral forces for lead and trail axles and high-rail and low-rail tie ends. Lives were converted to tie costs per ton-mile. For each route, the total tie cost per 1,000 net-ton miles was found using the assumed length of the route, the curvature distributions, and the distribution of hollow wheels for each removal case. Loaded and empty trains were modeled, assuming that an empty train gave one quarter the tie damage of a loaded train. The base-case tie costs (no hollow wheel removal) found for the east and west routes were very similar to costs established using the TRACS model during the Heavy Axle Load Phase II study, giving confidence in the calculations.

CALCULATION OF COSTS

Wheelset costs included labor costs, axle and wheel costs, bearing costs, and costs related to cars being out of service. All costs were based on figures from the Field Manual of the Association of American Railroads (AAR) Interchange Rules, the Office Manual of the AAR Interchange Rules, AAR circular letters on car-repair billing, and estimates from the former AAR R&T Engineering Economics Division. The method used to calculate increased wheel-maintenance costs for each hollow-wheel removal case was:

- Find the maintenance cycles needed over the life of a wheel, based on tread-wear rate.
- Calculate the average wheelset replacement cost, based on the number of maintenance cycles.
- Determine the life-cycle mileage of the wheel, based on the wear rate of the tread and the metal removed from the tread per maintenance cycle.
- Find the timing of cash flows from the average maintenance intervals based on the mileage per year.
- Determine the present value of cash flows.
- Calculate the equivalent uniform annual cash flow, based on the present value and the life of the wheel.
- Calculate the worst-case cost of executing each hollow-wear removal criterion. This was done by assuming, for example, that for the 4-mm removal study all 3-mm hollow wheels wore to 4-mm hollow wheels. This is conservative, as, based on AAR car-repair billing statistics, most wheels are taken from service for reasons other than wear.

SUMMARY OF OVERALL SYSTEM BENEFITS

For each removal limit, wheelset costs were subtracted from fuel, rail-wear, tie-life, and grinding benefits to get overall system benefits. Results are shown in Exhibit 3 for 1-wear wheels. The upper-bound line is for wheelset costs found by the method described above. These costs may be under-estimates. Although they use the very conservative assumption that, for example, all 3-mm wheels wear to 4-mm wheels, they assume that one wheelset is taken out for every two hollow wheels found. Hollow wheels often do not occur in pairs, and it is more likely that three wheelsets will be taken out for every four hollow wheels. Thus Exhibit 3 also shows a lower bound (worst-case) line assuming wheelset costs inflated by 50 percent. Exhibit 4 illustrates the estimated annual North American system benefits and wheelset maintenance costs (inflated by 50 percent) for 1-wear wheels.

It is seen that removal of hollow wheels is beneficial at hollow-wear values of 3 mm and

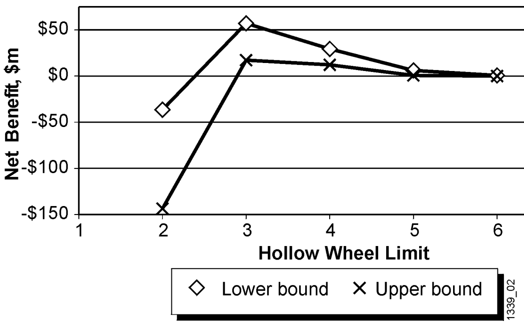

Exhibit 3. Effect of Hollow-Wheel Limit on North American System Benefits (1-Wear Wheels)

Removal limit, mm				
Costs	**2**	**3**	**4**	**5**
Wheelset	-$321m	-$120m	-$53m	-$17m
Benefits				
Fuel	$89m	$67m	$34m	$10m
Rail wear	$69m	$59m	$27m	$7m
Tie life	$7m	$5m	$2m	$0.3m
Grinding	$14m	$6m	$2m	$0.5m
Total	**-$142m**	**$17m**	**$12m**	**$0.5m**

Exhibit 4. North American System Annual Costs and Benefits for 1-Wear Wheels.

above. For 1-wear wheels, the estimated benefit from removing wheels at 3 mm ranges from $17 to $57 million. Most benefit derives from reduced fuel use and reduced rail wear. Benefits from longer wood-tie life and reduced grinding are less, but still significant. Results show that benefits rise for 2-wear and multiwear wheels.

CONCLUSIONS

- There are benefits from removing hollow wheels from service. Maximum benefit is achieved at a removal limit of 3-mm hollow wear, with smaller benefits for higher limits.
- A limit of 2 mm (0.08 inch) gives a negative benefit. This reflects the large numbers of moderately hollow wheels.
- The largest predicted benefits are related to decreased fuel use and decreased rail wear leading to longer rail life.
- The calculated lower-bound benefits are likely to be worst-case figures, and do not include benefits from reduced damage to special track and lower derailment risk.
- The finding that maximum benefits are achieved at a removal limit of 3 mm compares with 2-mm removal policies already introduced by QCM (Canada) and Spoornet (South Africa).

REFERENCES

[1] K Sawley and E Parker, “North American Wheel Profile Survey,” Technology Digest TD 98-003, Feb. 1998

[2] K Sawley, D Oliva-Maal and J LoPresti, “The Rolling Resistance of Severely Hollow-Worn Wheels,” Technology Digest TD 98-023, Sept. 1998

[3] K Sawley, “North American Rail Grinding: Practices and Effectiveness,” AAR R-Report R-928, Sept. 1999.

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