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The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Cost Analysis of Optimal Wheel Rim Thickness

Scott Cummings, Chris Pinney, Tom Guins (retired), and Nathan Wall (Railinc)

Key Findings:

- A small increase in the minimum 1-W rim thickness to an optimal value of 27/16 inch is projected to result in positive 15-year NPV of $50 million.
- The 27/16-inch rim yields a 30-year NPV of $115 million and annual benefits starting in the fourth year of implementation.
- Although the minimum allowable rim thickness for 1-W wheels is 24/16 inch, the actual average rim thickness exceeds 25/16 inch. The actual average rim thickness value was used as the baseline case against which all alternative rim thicknesses were compared.

Transportation Technology Center, Inc. (TTCI) conducted an analysis of the optimal 36-inch wheel rim thickness. The analysis found that a reduction in the actual average rim thickness of single-wear (1-W) wheels to the minimum specified value would result in a negative economic outcome for the industry. Wheel rims of 20/16 inch and 21/16 inch were found to produce an attractive 15-year net present value (NPV) due mainly to the assumed immediate reduction in the cost of new wheels. However, for these thin-rimmed wheels, the eventual lack of available turned wheelsets causes the annual costs to begin to exceed the benefits in the ninth and seventh years of implementation, respectively, and thus this path is not recommended. Also, any increase in rim thickness greater than the optimal 27/16-inch case will result in a diminishing economic return.

By combining data from wheel wear in service, material removal when truing at the wheel shop, and wheel removal causes, TTCI developed a methodology to project the percentage of new wheelsets and turned wheelsets that would be applied for any wheel rim thickness between 20/16-inch and 40/16-inch. These projections were scaled according to a shop scrap rate to account for wheels that are not turned and reapplied even though they may theoretically have sufficient remaining rim thickness. This methodology allows for the projections to match the actual percentage of new wheelsets and turned wheelsets that are applied for 1-W and two-wear (2-W) wheelsets.

This work is part of the Association of American Railroads (AAR) Strategic Research Initiatives program.

It is important to discern between the total life of a wheel from manufacture to scrap, and the application life of a wheel from the time it is placed in service until it is removed for cause. In some cases, wheels can be re-profiled and reapplied one or more times throughout their life. AAR specifications[1] allow different wheel rim thicknesses for new wheels, including 1-W, 2-W, and multi-wear (M-W). Table 1 shows critical dimensional differences between these wheel designs. Re-profiled wheels must have rim thickness greater than or equal to the reapplication limit when they are placed back into service.

Table 1. Wheel minimum dimensional parameters, all units are 1/16 inch

Design	1-W	2-W	M-W
New Rim Thickness at Gage Line	24	32	40
Net Rim Material to Reapplication Limit	8	16	24
Net Rim Material to Condemning Limit *	10	18	26

** For 28-, 36-, and 38-inch diameter wheels*

The majority of new wheels produced in North America are 1-W design because they have the lowest initial cost. They also are the lightest option, resulting in a weight savings per wheel of about 90 pounds compared to a 2-W wheel design for 36-inch nominal diameter, according to a supplier of wheels. The potential range of wheel diameter of a 1-W wheel is less than that of other wheel designs, and many double-stack cars are designed with the intention that only 1-W wheels be used in order to maximize the available clearances. This analysis focuses on nominal 36-inch diameter wheels because they are the most common size and because they are not typically used for double-stack cars, thereby avoiding vertical car clearance issues.

It is important to note that the dimensions in Table 1 are minimum values and rim thicknesses on new wheels are allowed to exceed the dimensions in Table 1. Actual rim thicknesses are recorded to the nearest 1/16 inch in the AAR Car Repair Billing database when wheelsets are applied and removed. Analysis of this data shows that the average rim thickness for new 1-W and 2-W wheels is 25.4/16 inch and 32.4/16 inch, respectively.

ANALYSIS

TTCI previously has analyzed the potential effects of eliminating the 1-W wheel, thereby effectively requiring that all new wheels be 2-W design.[2] To conduct that analysis, TTCI gathered information related to the amount of rim material lost during service and during reprofiling. This data was segregated by the various removal causes of the wheelsets. For example, based on data collected at two wheel shops, it was determined that 0.47 inch was the average amount of rim material removed when truing a wheelset with impact loads of 90 kips or greater. This methodology allowed for calculation of the expected number of applications as a function of wheel rim thickness by looking at all possible permutations of removal causes for up to five applications per wheelset.

For the current analysis of the optimal wheel rim thickness, TTCI leveraged the previous analysis methodology, updated relevant values, and tightened the gap between rim thickness steps from 8/16 inch to 1/16 inch. Additionally, wheels with as-manufactured rim thicknesses as small as 20/16 inch were considered. Table 2 shows a breakdown of the percentages of wheelsets removed for common Why Made Codes (WMCs)[3] for the calendar year 2017 and the rim thickness loss values used in this analysis.

Table 2. Rim material loss

WMC	Percent Cause for Wheelset Removal	Nominal Rim Material Loss per Application	Positive Tolerance Rim Material Loss per Application	Negative Tolerance Rim Material Loss per Application
11	18.3%	0.250	0.313	0.188
60	8.1%	0.938	1.000	0.875
61	18.5%	0.528	0.591	0.466
63	0.1%	0.500	0.563	0.438
64	4.3%	0.500	0.563	0.438
65	40.4%	0.591	0.653	0.528
75	6.0%	0.591	0.653	0.528
76	0.5%	0.528	0.591	0.466
78	1.4%	0.528	0.591	0.466
Other	2.5%	Assume wheels are scrap when removed		

The previous analysis assumed that every wheelset removed for a particular WMC experienced the same amount of wear in service and required the same depth of cut when truing. Although this assumption had minimal effect when considering rim thicknesses that differ by 8/16 inch, it must be relaxed to produce a more realistic analysis when comparing wheels with rims differing by only 1/16 inch. Thus, a tolerance of ±1/16 inch in the amount of rim material lost by wear and truing was considered for every wheelset removal WMC. The nominal value for material loss was assumed to occur in 50 percent of the cases. The positive and negative tolerance values for material loss were each assumed to occur in 25 percent of the cases.

For any given starting rim thickness, this methodology allows for the calculation of the percent of wheelsets that would be expected to have sufficient rim material to be trued and reapplied one or more times. However, separate consideration must be given to wheels that may be removed for cause, arrive at the wheel shop with sufficient remaining rim material to be turned, but are scrapped for another reason. For example, if the wheelset back-to-back spacing is found to be out of tolerance, or if one of the wheels fails the ultrasonic test for internal discontinuities, the wheels will be removed from the axle and scrapped regardless of remaining rim thickness. Likewise, in some wheel shops, if the axle needs maintenance, the wheels will be pressed off and scrapped. A wheel shop also must consider the business risk of spending the time and effort to true a wheelset with marginal rim thickness and tread shells of uncertain depth. To account for wheelset losses such as these and to make sure the analysis corresponds with reality, the predicted values must be compared to existing industry statistics.

Every applied wheelset includes either new wheels or turned wheels. Figure 1 shows the percent of turned wheelsets applied as a function of as-manufactured rim thickness.

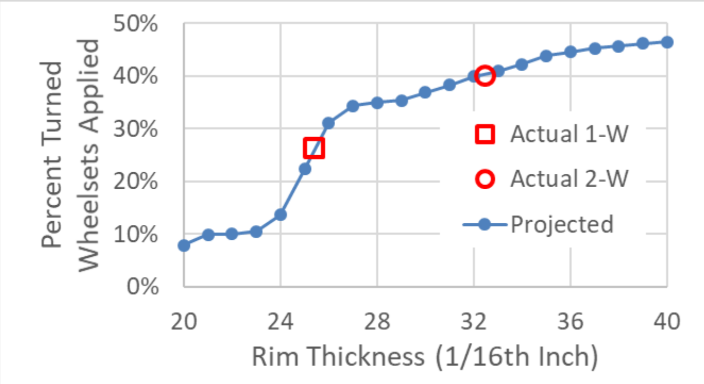

Figure 1. Steady state percent turned wheels applied

The actual values for 1-W and 2-W wheels (26.3 percent and 40.1 percent, respectively) are sourced from a recent 12-month period of data from the component tracking data System. This is used to record many parameters about each applied wheelset including whether the wheels are new or turned. As stated previously, new nominal 1-W and 2-W wheels have average applied rim thicknesses that are slightly larger than the minimum values and this is reflected in the figure. Also included in Figure 1 are the projected percent turned wheelset applied percentages for various wheel rim thicknesses. These are the projected steady-state values that would eventually result if all new wheels were produced to the corresponding rim thickness. It can be observed that the projected values intersect with the actual values for both 1-W and 2-W wheels. This is not by accident. Rather, an additional factor was included in the analysis to account for the percent of wheelsets that are scrapped at the wheel shop even though sufficient rim thickness remains to meet the reapplication requirement after turning. This factor was iterated until the projected values aligned with the actual values. This occurred at a shop scrap rate of 43 percent. Though this may appear high, it is not beyond the bounds of reason, as some shops report scrap rates of 25 percent just due to axle issues alone.

It can be observed from Figure 1 that the percentage of turned wheelsets applied varies non-linearly with wheel rim thickness. This is the result of having many of the common causes of wheelset removal resulting in a rim material loss per application of just a bit more than 8/16 inch. Because the 1-W wheel design calls for a minimum of 8/16 inch of net rim material to the reapplication limit, wheels produced to this minimum requirement would not typically be expected to have sufficient remaining rim material to turn and reapply. Hence the name "single wear." However, the actual average rim thickness of nominal 1-W wheels appears to be on a steep slope in Figure 1. The projected percent turned wheelsets applied has a strong dependence on rim thickness for values between 23/16 and 27/16 inch.

ANALYSIS OF COSTS AND BENEFITS

The primary economic benefit of thicker rim wheels results from the increase in the number of turned wheelsets available for application to freight cars. For thinner rim wheels, the primary economic benefit arises from a reduced cost for new wheels.

It is believed the price premium between a wheelset with new 1-W wheels and one with new 2-W wheels is in the range of approximately $265 per wheelset as reflected in the AAR Office Manual of the Interchange Rules.[4] Using the weight differential and price differential between 1-W and 2-W wheels, a linear relationship was assumed such that the price of a wheel is a function of its weight. Wheel weights and prices are interpolated or extrapolated based on the values for 1-W and 2-W wheels.

There is a cost due to the increased tare weight of cars equipped with thicker rim wheels. The increase in weight is 720 pounds for a four-axle car with wheels of 32/16-inch rim thickness compared to a car with wheels of 24/16-inch rim thickness. This requires an increase in the number of trains resulting in an associated cost increase. Similar to the wheel prices, the capacity costs are interpolated or extrapolated as needed for each analyzed wheel rim thickness value.

Figure 2 shows the projected net economic results of various wheel rim thicknesses. The 15-year NPV reaches its maximum of $106 million at the thinnest rim analyzed — 20/16 inch. Positive 15-year NPV also is found at 21/16 inch. Local optimums in the 15-year NPV occur at 26/16 and 27/16 inch with a value of $50 million. The 30-year NPV reaches its maximum of $115 million at 27/16 inch.

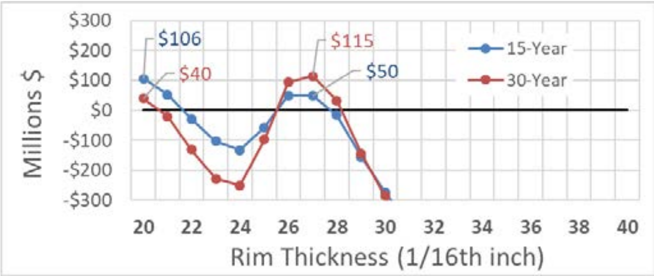

Figure 2. Net present value economic projections

To reach full implementation, a significant transition period will be experienced. Figure 3 shows the projected annual cost or benefit of cases with a positive 15-year NPV.

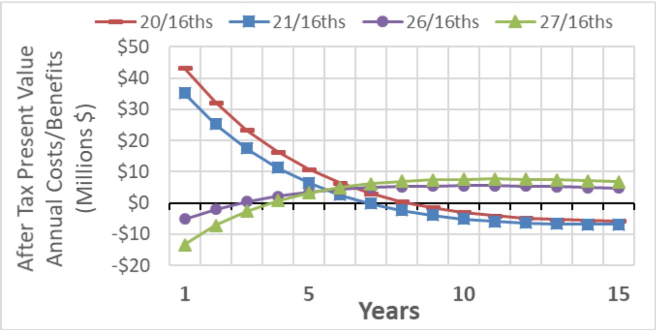

Figure 3. Phase-in period, annual costs/benefits

For the 20/16-inch rim, the applied wheelsets with new wheels would be expected to be lighter and cheaper starting in the first year of implementation. The costs associated with not having as many turned wheelsets available are phased in over time as wheelsets currently in service are replaced with wheelsets with thinner rims. This would eventually drive up the average price of a wheelset. In the ninth year of implementation the annual costs exceed the benefits for this case. The story is similar for the 21/16-inch rim.

For thicker rim wheels, there will be a price premium starting in the first year of implementation, but the benefits phase in as wheelsets are removed for cause over their service life. For the 27/16-rim, beginning in the fourth year, the annual benefits due to more available turned wheelsets exceed the increased costs due to new wheel prices and capacity reduction. The story is similar for the 26/16-inch rim.

CONCLUSION

An analysis of the optimal wheel rim thickness provides several key findings. A small increase in the minimum 1-W rim thickness to an optimal value of 27/16 inch is projected to result in positive 15-year NPV of $50 million, 30-year NPV of $115 million, and annual benefits starting in the fourth year of implementation. Conversely, a reduction in the actual average rim thickness of 1-W wheels from more than 25/16 inch to the minimum AAR specified value of 24/16 inch would result in a negative economic outcome for the industry. Although the 15-year NPV is positive for wheels with rim thickness equal to 20/16 and 21/16 inch, the annual costs begin to exceed the benefits in the ninth and seventh years of implementation, respectively.

References

1. Manual of Standards and Recommended Practices, M-107/M-208 Wheels, Carbon Steel. 2012, AAR, Washington, DC.
2. Cummings, S., T. Guins, and D. Urgup, "Cost Analysis of Using Thicker Wheel Rims in Freight Operations" Technical Digest TD17-013, June 2017, AAR/TTCI, Pueblo, CO.
3. Field Manual of the AAR Interchange Rules, Rule 41 Wheels, 2019, AAR, Washington, DC.
4. AAR Office Manual of the Interchange Rules. AAR, Washington, DC.

For comments or questions about this publication, contact Scott_Cummings@aar.com