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High Impact and Thin Rims Broken Wheel Analysis

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Summary

As part of the Association of American Railroads' (AAR) Strategic Research Initiatives Program, Transportation Technology Center, Inc. (TTCI) analyzed broken and shattered rim data, including vertical split rims, to identify wheels with an increased risk of breaking due to high impacts and thin rims. This is completed using risk assessment, a method of quantifying the risk of an event — a broken rim in this case — compared to the general population of cars in revenue service.

Results of the risk assessment support the influence of the combined rim thickness and dynamic vertical load. Generally thin rims with high impact wheels are at greater risk of breaking than thick rims with little or no worn tread conditions.

The highest risk wheels are those identified under the following conditions and account for one-third of the identified broken wheels included in the study:

- Rim thickness of 12/16 inch and dynamic vertical forces of 10 or more kips
- Rim thickness of 13/16 inch and dynamic vertical forces of 30 or more kips
- Rim thickness of 14/16 to 16/16 inch and dynamic vertical forces of 50 or more kips

Dynamic instead of peak vertical forces help identify the 25 percent of the broken wheels that occurred under empty conditions with no recent loaded wheel impact load detector (WILD) passes.

While about 75 percent of these wheels meet one of the existing WILD or thin rim rules in the *Field Manual of the AAR Interchange Rules*, a composite rule of WILD with thin rim measurements could be used proactively to select the identified wheels from the general population.



INTRODUCTION

In 2014, there were nine Federal Railroad Administration reportable derailments with the primary cause of broken rims.¹ Current practices for the prevention of broken wheel derailments rely on manual inspections and the removal of high impact wheels from service. There are several technologies in limited use or still under development for the wayside detection of cracked wheels with automated cracked wheel detection systems.²

Characteristics of some broken wheels are thinning rims combined with increased dynamic loads due to wheel tread conditions (Figure 1). The *Field Manual of the AAR Interchange Rules* implemented the below condemning limits separately for thin rims and high impact wheels that reduce the risk of broken wheels.³

- Thin rim 3/4 inch (12/16) or less for 30- and 33-inch wheels. (Rule 41.1h(1))
- Thin rim 7/8 inch (14/16) or less for 28-, 36-, and 38-inch wheels. (Rule 41.1h(2))
- WILD at least 90 kips condemnable at any time (WM 65) or 80 to 89.99 kips condemnable on a repair track (WM 61)



Figure 1. Wheel with a Broken Rim

The purpose of this research is to identify wheels with an increased risk of breaking due to a combination of high impacts and thin rims.

ANALYSIS

The analysis comprises of risk assessment, a method of quantifying the risk of an event — a broken rim in this case — compared to the general population. Risk assessment can be applied to engineered systems that fail as well as transactional systems characterized by failures in a process step or a malfunction.

The risk assessment includes two datasets: (1) broken rim data and (2) wheel information representing the cars in revenue service. Three years of broken wheel data (2011 through 2013 totaling 813 records) are used from Car Repair Billing (CRB) and the MD-115 AAR Failed Wheel Report (AAR *Manual of Standards and Recommended Practices, Wheels and Axles*). The broken wheel rim thickness data is merged with WILD data to get the highest peak and dynamic vertical forces 30 days before the wheel is broken. WILD peak is the maximum vertical forces for a wheel and dynamic is the difference between the peak and average vertical (wheel weight) through the detector. Peak and dynamic measure the additional forces from a worn or out of round wheel. The broken wheel data is filtered as follows:

- Broken, shattered, or vertical split rims (VSRs) are included.
- Duplicate wheels between CRB and MD-115 or records with incomplete information are excluded.
- Southern and straight plate wheels are excluded because of special circumstances handled by existing rules.⁴

The MD-115 and CRB include why made codes for broken and shattered rims. VSRs are a subset of these broken wheels without a separate why made code. VSRs and their failure mode were previously examined for root cause.⁵

Dynamic vertical forces are used in the analysis to maximize the number of opportunities to identify wheels by risk category. Using peak vertical forces would reduce the opportunities by 25 percent for the broken wheels with no recent loaded car history.

- 25 percent of broken wheels have only empty WILD passes 30-days prior to removal
- 12 percent of broken wheels have no recent WILD passes

The representative population (REP_POP) of high impact wheels and thin rims measurements are collected from wayside WILD and wheel profile detectors (WPD). WPDs are automated machine vision systems utilizing cameras and/or lasers to measure critical dimensions on the wheels and wheel sets.

WILD and WPD data are merged by wheel, with over 98.8 percent of the train passes less than 2-minutes apart between both detectors for a total of 4.1-million wheels. Some of the cars passed the detectors multiple times, so the dataset is reduced to unique wheels in the dataset totaling 1,775,648 unique wheels (244,097 cars in the REP_POP). This prevents overweighting the analysis with duplicate wheels.

Comparing the frequency of car types between Umler (Figure 2) and the REP_POP (Figure 3), both have the same first three car types, representing about 60 percent of the cars. The REP_POP has more vehicular flat cars (V) and stack cars (S).

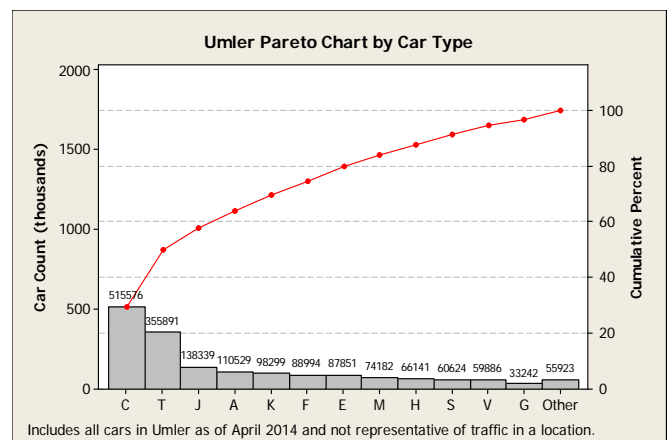


Figure 2. Umler Pareto Chart by Car Type

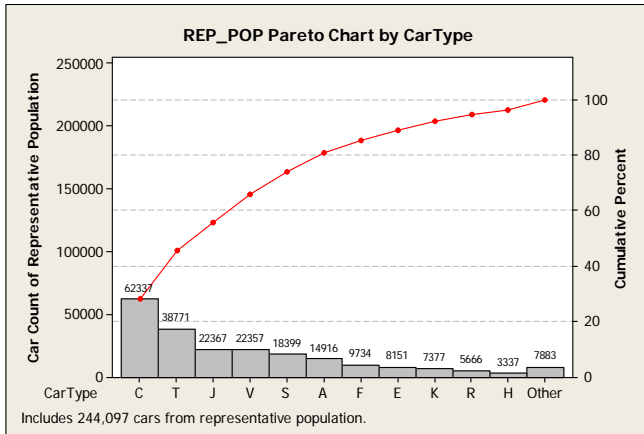


Figure 3. REP_POP Pareto Chart by Car Type

Figure 4 is a histogram of broken wheels by rim thickness with many wheels with rim thicknesses less than 17/16 of an inch. The effect of the spike in broken wheels between 22/16 and 24/16 of an inch is discussed further in the results.

Figure 5, in contrast, has few wheels with rim thickness less than 17/16 inch, with the majority between 21/16 and 24/16 of an inch.

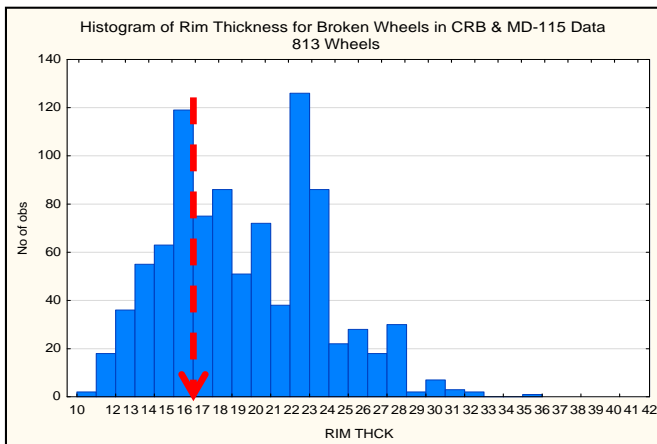


Figure 4. Histogram of Broken Wheels by Rim Thickness

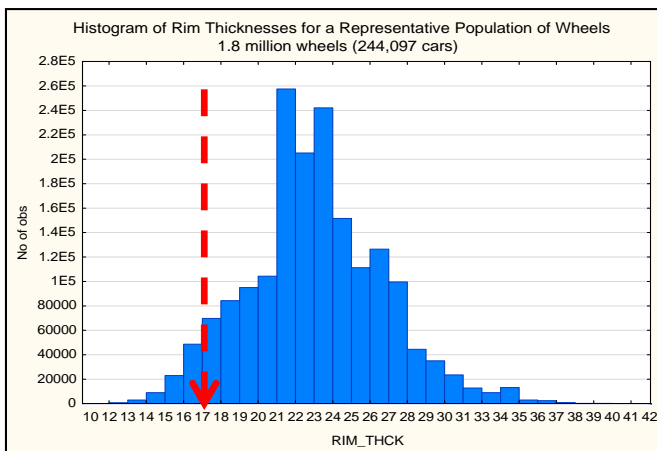


Figure 5. Histogram of REP_POP by Rim Thickness

RESULTS

Using the AAR *Field Manual* limits for rim thickness and WILD peak values, the risk analysis examines the following categories.

- Rim Thickness — 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27 sixteenths of an inch
- Dynamic Vertical — 0 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 50, and 50 to 60 kips

The number of broken wheels is compared to the REP_POP by dynamic vertical force to the same wheel’s rim thickness using the following equation.

$$Nominal\ Change\ in\ Risk = \left[\frac{\left(\frac{Broken\ Wheels\ in\ Category}{Total\ Broken\ Wheels} \right)}{\left(\frac{Wheels\ in\ Service\ in\ Category}{Total\ Wheels\ in\ Service} \right)} - 1 \right] \times 100\%$$

In addition, binomial hypothesis testing is completed to compare each category’s broken wheel rate to its wheels in service rate to verify a statistical difference with 95 percent confidence (Table 1).⁶ For example, the rim thickness of 25/16 of an inch with dynamic vertical forces between 30 and 40 (brown outlined cell) has no statistical difference.

The lower left corner has the lowest risk, down to 96 percent less risk than the representative population. These are thick rims with low dynamic forces.

The upper right corner has the highest risk, from 5,000 percent up to 218,000 percent nominal higher risk (50 to 2,000 times more risk) than the representative population. These are thin rims with high dynamic forces for their rim thicknesses.

Returning to the spike in broken wheels from Figure 4, between 22/16 and 24/16 of an inch, there is little effect on the risk assessment in Table 1. The rim thicknesses between 22/16 and 24/16 in Table 1 for dynamic vertical forces between 20 and 50 have some higher percentage risks. These risks are only incrementally higher because of the larger population of wheels in the REP_POP.

Table 2 shows the number of wheels at risk in each category instead of the percentage of increased risk, as Table 1 shows.

The number of wheels in the red risk group (top right) is 337 wheels. The number of wheels in Umler is about eight times higher than the REP_POP to give an estimate of about 2,700 wheels at highest risk group in North America. About 75 percent of the highest risk wheels meet existing opportunistic or condemnable AAR rules for WILD peak kips (AAR 41.A.1.r or 41.A.2.e) or thin rims (AAR 41.A.1.h).³

Table 1. Risk Analysis (Detailed Distribution Analysis)

Likelihood for Wheel to Break compared to Representative Population						
Rim Thickness in 16th Inch	Dynamic Vertical Forces					
	0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60
12				50x or more risk		
13				50x or more risk		
14				50x or more risk		
15			10 to 40x more risk			
16			10 to 40x more risk			
17			5 to 10x more risk			
18			5 to 10x more risk			
19		Risk like general population				
20		Risk like general population				
21		Risk like general population				
22		Risk like general population				
23		Risk like general population				
24	Less than ½ the risk					
25	Less than ½ the risk					
26	Less than ½ the risk					
27	Less than ½ the risk					

Table 2. Risk Analysis (with number of wheels in the representative population in each cell)

Number of Wheels in the Representative Population						
Rim Thickness	Dynamic Vertical Forces					
	0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60
12	598	40	20	6	6	1
13	2,497	183	105	43	30	7
14	7,493	788	349	199	93	23
15	18,754	2,528	992	494	161	63
16	38,850	6,254	2,189	865	309	98
17	55,626	9,278	2,981	1,204	432	123
18	67,627	10,912	3,596	1,366	508	163
19	76,810	12,177	3,862	1,473	493	158
20	85,309	12,598	4,138	1,536	538	149
21	91,692	13,248	4,282	1,750	618	196
22	117,323	18,321	5,870	2,563	993	375
23	163,433	27,958	8,537	3,349	1,216	417
24	198,034	31,516	8,355	2,902	919	292
25	122,747	20,282	5,635	1,980	680	220
26	85,070	18,443	5,147	1,694	574	164
27	101,473	18,484	4,551	1,365	408	133

CONCLUSION

The risk assessment for broken or shattered rims supports the influence of the combined rim thickness and dynamic vertical load. Generally thin rims with high impact wheels are at greater risk of breaking than thick rims with little or no worn tread conditions.

The highest risk wheels, those with over a 5,000 percent nominally greater risk (50 times or more risk) than the representative population, are identified under the following conditions and account for one-third of the identified broken wheels included in the study.

- Rim thickness of 12/16 inch and dynamic vertical forces of 10 or more kips
- Rim thickness of 13/16 inch and dynamic vertical forces of 30 or more kips
- Rim thickness of 14/16 to 16/16 inch and dynamic vertical forces of 50 or more kips

With 25 percent of the broken wheels occurring under empty conditions with no recent loaded WILD detector passes, using WILD peak vertical forces would reduce the number of opportunities for removing at risk wheels.

About 75 percent of the highest risk wheels (in red in Tables 1 and 2) meet one of the existing WILD or thin rim rules in the AAR *Field Manual*. Due to the large number of opportunities for wheel removals, a composite rule of WILD with thin rim measurements could be used proactively to select wheels at increased risk of breaking.

Additionally the remaining 25 percent of the wheels can be identified with a composite rule of WILD and thin rim measurements. A car owner can take the opportunity to identify and remove these remaining increased risk wheels, but there is currently no AAR Interchange Rule for removal of these wheels.

REFERENCES

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