AN ANALYSIS OF WHEEL REPAIR DATA FOR A COAL CAR FLEET

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In addition to supporting mechanical loads, railroad wheels serve an important function as brake drums in freight car air brake systems. Railway wheel removals in service can be caused by many factors including tread wear, flange wear, improper use of the handbrake, defective air brakes, manufacturing defects, and various other reasons. Past reviews of Association of American Railroads (AAR) car repair billing (CRB) data show that many North American freight car wheel removals are for wheel/rail sliding-related defects such as spalling, slid flats, built-up-tread and out-of-round. In this paper, year 2001 wheel removal data for a fleet of coal cars owned by a major Midwestern utility are reviewed and compared. Differences between wheel removal data for steel and aluminum cars in the coal car fleet are discussed, with emphasis on possible causes. Also, differences between AAR CRB wheel removal data and wheel removal data for the coal car fleet are discussed, with emphasis on possible causes. Recommendations are also offered.

INTRODUCTION

When the decision was made to allow 36-inch wheels in 286K gross rail load (GRL) service, a reasonable conclusion was that an increase in wheel service related defects would result. Freight car wheels in 286,000 pounds GRL service originally were analyzed and designed for 263,000 pounds GRL service. AAR S-660 procedures in fact still use the lower 263K GRL load values to obtain approval for new wheel designs. AAR CRB data can be used to analyze wheel failures and removal trends. However, this set of data is becoming less and less representative of the entire wheel population over time. With today's larger railroads more wheel repairs are done on line, and more wheel repairs are performed at private car shops. These removals are not included in the CRB data. To obtain a better understanding of the effects of higher GRL, car type, etc., on wheel removals, the year 2001 wheel repair data of a major Midwestern utility (hereafter referred to as the Utility) were analyzed.

BACKGROUND INFORMATION AND FLEET DESCRIPTION

The Utility operates unit coal trains (approximately 125 cars per train) from the Powder River Basin to two rail-served electric generating stations in the Midwestern United States. One of the plants receives approximately ¾ of a train per day (steel cars), and the other plant receives 1-1/2 trains per day of aluminum cars. All cars have a service mileage of approximately 9,000 miles per month. The Utility uses a private car repair shop in close proximity to the destination generating stations as a "home" shop (hereafter referred to as the Home Shop), and makes every effort to have as many repairs done at this facility as possible. This allows for better maintenance planning and control and helps to keep overall freight car maintenance costs, including wheel removal costs, generally lower.

The Utility's coal car fleet consists of 1,350 aluminum cars and 812 steel cars. The aluminum cars operate at a load level of 286,000 pounds GRL while the steel cars operate at a load level of 270,000 pounds GRL. All of the aluminum cars have body mounted brakes while the steel cars have truck mounted brakes. Aluminum cars are equipped with the Elcon National 50-50 empty load system and the steel cars have truck-side empty load devices. Both fleets experience similar mileage during the course of a year. Hand brakes are applied to some cars when the trains are placed at the destination electric generating stations.

The Home Shop uses a WABCO automated air test system for air brake system diagnostics. For maintenance repairs, new wheels are specified and premium specification bearings (fitted backing ring/fitted application) are used. Also, the coal cars are equipped with premium components, such as premium spring packages. If repeat replacements of components are noted on a car, an investigation is conducted to determine the root cause. It is certainly fair to say that the fleet is very well equipped and maintained.

2001 FLEET WHEEL REPAIR DATA OVERVIEW

Two sets of year 2001 wheel repair data were made available to the author by the Utility in printed, non-electronic form. The first set of data is from the Home Shop and consists of wheel changeouts made at that facility. These data are therefore not included in overall AAR CRB counts. The second set of data consists of all wheel maintenance repairs for the Utility, including those performed by railroads. The railroad repairs to private coal cars are included in overall AAR CRB counts. Wheel repairs by railroad were extracted from the second data set. All wheels were 1-wear, heat-treated, curved plate wheels from cast and forged manufacturers. No wheel failures were noted.

A summary of wheel removal data for both car sets is shown in Table 1. The data show that most wheel repairs (80%) are conducted at the Home Shop, and that the aluminum cars have more total wheel replacements than the steel cars.

Type of Coal Car	Number Of Cars With Wheel Changeouts			
	Railroad A	**Railroad B**	**Home Shop**	**Total**
Aluminum	191	32	570	793
Steel	14	9	405	428
Total	**205**	**41**	**975**	**1221**

Table 1. Number of cars with wheel repairs during 2001.

Table 2 shows the AAR Why Made Codes that are contained in the fleet data for year 2001 (Ref. 1):

Why Made Code	Description From AAR Field Manual, Rule 41
11	Removed in good condition account of associated repairs
25	Owner's request
60	Flange thin
64	Flange high
73	Rim thin
75	Tread shelled
78	Tread slid flat
90	Mate wheel scrapped
98	Wheel not meeting reapplication limits

Table 2. AAR Why Made Codes in the Utility fleet data.

Table 3 shows the number of wheel changeouts by AAR Why Made Code for the two billing railroads (RR A and RR B) and the Home Shop.

Repair Location & Car Type	AAR Why Made Codes									
	11	**25**	**60**	**64**	**73**	**75**	**78**	**90**	**98**	**Total**
RR A - Alum.	0	0	0	7	0	173	0	0	0	180
RR A - Steel	0	0	0	0	0	14	0	0	0	14
RR B - Alum.	0	0	0	0	0	32	0	0	0	32
RR B - Steel	0	0	0	0	0	9	0	0	0	9
Home Shop - Alum.	751	53	45	553	11	169	2	49	2	1635
Home Shop - Steel	488	1	20	423	7	51	0	63	0	1053
Totals	**1239**	**54**	**65**	**983**	**18**	**448**	**2**	**112**	**2**	**2923**

Table 3. Wheel changeouts by AAR Why Made Code.

Removals for Why Made Codes 60, 64, 73 and 98 are wear related. It was noted that all of the wheels removed for Why Made Code 25 (all at the Home Shop) were produced by one wheel manufacturer. The effort to remove these wheels was deliberate on the part of the fleet manager. Why Made Code 11 and 90 changeouts are generally described by this author as "Administrative" wheel removals since the replacement occurs for reasons other than a defect on the wheel removed. Why Made Code 75 can encompass wheel removals for three basic causes: 1) shelling, 2) spalling and 3) thermo-mechanical shelling. These causes will be discussed in more detail in the next section.

WHEEL SHELLING/SPALLING

Much has been published in the literature regarding the causes of Why Made Code 75, wheel shelling. True wheel shelling is a rolling contact fatigue phenomenon that is caused by wheel/rail contact stresses that generate a maximum sub-surface shear stress. These high sub-surface shear stresses cause fatigue cracks to initiate, grow and eventually lead to cracking of pieces off the wheel tread in service. True shelling is similar to what occurs in fatigue failures of bearing races. True wheel shelling does occur on selected railway service lanes in North America.

Thermo-mechanical shelling is also seen on selected railway service lanes that have a combination of high wheel loads and severe tread braking. Prolonged brake heating can lead to a reduction in the steel's yield strength and subsequent fatigue damage from wheel/rail loads.

However, it is now generally accepted in the railroad industry that most wheel shelling is actually wheel spalling, which is caused by sliding of the wheel on the rail. When the wheel slides, the small patch of steel in contact with the rail is heated, and if heated to a high enough temperature, is austenitized. The heated area is then quickly quenched by the remaining cold body of the wheel and a patch of hard, brittle martensite results. Cracking and eventual fracture of pieces off the wheel tread occurs in service, and such tread defects can lead to high impact loads. Shelling/spalling defects can become quite severe and can lead to extensive damage around the wheel tread.

WHEEL SLIDING

Wheel slides occur when the retarding force between the wheel and brake shoe is greater than the force between the wheel and rail (adhesive force) (Ref. 2). The retarding force depends on the brake shoe force and friction between the shoe and wheel tread. If a car is empty, there is less adhesive force between wheel and rail and the tendency for the wheel to slide is greater. Also, if the amount of brake shoe force is greater, wheel sliding is more likely. Many factors affect the tendency of wheels to slide and some are listed below:

- Car moved with handbrake applied
- Excessive empty braking ratio
- Malfunctioning empty/load device
- Defective air brake systems
- Low wheel/rail coefficient of friction
- Rail condition issues
- Wheel profile issues
- Truck steering issues
- Etc.

WHY MADE CODE 75 REMOVALS BY WHEEL POSITION

Previous investigations have suggested that operating cars with handbrakes applied is a major cause of wheel sliding, hence tread defects such as spalling. Thus, the position of wheel removal was studied to determine if this was the case for the Utility's fleet. For the aluminum cars with body mounted brakes, all wheels would slide if handbrakes were a factor. However, for the steel cars, with truck mounted brakes, a high incidence of removals on the 1st and/or 2nd axle would suggest a handbrake-related condition. Table 4 shows the position of wheel removal on the coal car for Why Made Code 75 (wheel shelling) for the railroad and Home Shop repairs.

Repair Location and Car Type	Why Made Code 75 - Position Of Wheel Removal On Car							
	R1	**R2**	**R3**	**R4**	**L1**	**L2**	**L3**	**L4**
RR A - Aluminum	15	21	34	26	17	21	20	19
RR A - Steel	2	1	1	0	1	4	3	2
RR B - Aluminum	3	7	1	3	4	3	6	5
RR B - Steel	2	1	1	0	0	2	1	2
Home Shop - Aluminum	20	23	20	19	24	22	19	22
Home Shop - Steel	5	12	3	5	8	1	8	9
Total (448) WM 75	**47**	**65**	**60**	**53**	**54**	**53**	**57**	**59**

Table 4. Wheel shelling removals by position on car.

A statistical technique called "chi-square" was then used to determine if there is a statistically significant difference in the number of Why Made Code 75 wheel removals by axle position for the Utility's steel and aluminum car groups. Chi-square analysis is used for attribute data (e.g.: "good" and "bad") and was performed using the Mintab® software package. Removals on axles 1 and 2 were considered "bad" and those on axles 3 and 4 were considered "good." For chi square, the null hypothesis is that there is no difference between wheel removals by axle position for the two car types. If a "P-value" of less than 0.05 is calculated, then there is a difference in removals by axle positions between the steel and aluminum car groups. The P value for the comparison was calculated to be 0.472, indicating that there is no statistically significant difference in Why Made Code 75 removals between the 1st and 2nd axle positions of the steel cars compared to the 1st and 2nd axle positions of the aluminum cars. Therefore, the steel cars are not experiencing a statistically significantly greater number of handbrake related wheel shells/spalls. Overall, some percentage of Why Made Code 75 wheel removals are likely occurring on the Utility's fleet due to handbrake related sliding.

OVERALL FLEET WHEEL REMOVALS

Chi-square was then used to determine if there is a statistically significant difference in the number of wheel removals between the Utility's steel and aluminum car groups. For the analysis, coal cars with 2001 wheel removals of any kind were taken as "bad" while cars with no 2001 wheel removals were considered as "good." Of the 1350 aluminum cars, 793 had wheel removals in 2001. Of the 812 steel cars, 427 had wheel removals in 2001. Table 5 shows the Minitab® output data for the chi-square analysis.

Car Type		Number Of Cars With No Wheel Removals ("Good")	Cars With Wheel Removals ("Bad")	Total Number Of Cars
Aluminum	Actual	557	793	1350
	Expected	588.21	761.79	
Steel	Actual	385	427	812
	Expected	353.79	458.21	
Chi-sq. = 1.656 + 1.278 + 2.752 + 2.125 = 7.811				
Degrees of Freedom = 1, P-value = 0.005 (thus samples are statistically different)				

Table 5. Output data for chi-square test – all wheel removals by car type.

The P-value for the chi-square test in Table 5 is shown to be well below 0.05. Therefore there is a statistically significant difference between overall wheel removals for the steel and aluminum car groups. The majority of variation in the chi-square total value comes from the number of wheel removals on the aluminum cars, followed by the number of wheel removals on the steel cars. Note that the aluminum cars are performing slightly worse than expected (793 actual cars vs. 761.79 expected), while the steel cars are performing slightly better than expected (427 actual cars vs. 458.21 expected).

WHY MADE CODE 75 REMOVALS AND WHEEL LIFE

An effort was then made to determine if the steel and aluminum cars had a difference in wheel mileage (life) for the shelled wheels. Data were manually entered into an Excel spreadsheet for manipulation and calculations. Calculations of a mileage life for other Why Made Codes was not attempted. The author feels that a difference between car types (such as a gross rail load related effect or a wheel sliding related effect) would best manifest itself via Why Made Code 75.

For the wheel life calculations, the wheel manufacturing date from the serial number was used as the life “starting” date and the wheel removal date was used as the “ending” date. The author realizes that wheels may not enter service in the same month of manufacture, however this date was chosen rather than use an arbitrary “delay factor” that would likely yield similar results. Then, the number of months in service for each wheel was calculated and multiplied by 9,000 miles per month (the estimated mileage for each car in the fleet). Mean mileage and mean months in service values were next calculated for the steel cars and the aluminum cars.

Some wheels (17 total) were deleted from life calculations due to 1) missing data or 2) a manufacturing date too old to be an original wheel on the car. The latter wheels had likely been changed out previously in service. The mean mileage and mean months in service values for the steel cars are 517,000 miles and 57 months, respectively. The mean mileage and mean months in service values for aluminum cars are 457,000 miles and 51 months, respectively.

The spreadsheet columns of mileage and months in service data for aluminum and steel cars were then entered into Minitab® statistical software package to compare the samples using the “2 sample t-test.” This test method compares the means of two different samples of variable data. For this statistical treatment, the null hypothesis assumes that there is no difference in the mileage life of the two car types. If a “P-value” of less than 0.05 is calculated by the Minitab® software, then there is indeed a difference between the groups of aluminum and steel cars. The 2-sample t-test produced a P-value of 0.006, meaning that there is a statistically significant difference between the wheel life of steel and aluminum cars.

A chi-square analysis (again using the Minitab® software) was then used to determine if there is a statistically significant difference in the incidence of wheel shelling between the Utility's steel and aluminum car groups. For the analysis, shelled wheels were taken as "bad" and all other AAR Why Made Codes were taken as "good." All Why Made Code 75 wheel removals from the Home Shop, Railroad A and Railroad B were used for the calculations. Table 6 shows the Minitab® output data from the chi-square test.

Car Type		Other Why Made Code Removals "Good"	Why Made Code 75 Removals "Bad"	Total Wheel Removals, All Why Mades
Aluminum	Actual	1473	374	1847
	Expected	1563.92	283.08	
Steel	Actual	1002	74	1076
	Expected	911.08	164.92	
Chi-sq. = 5.285 + 29.198 + 9.072 + 50.120 = 93.676				
Degrees of Freedom = 1, P-value = 0.000 (thus samples are statistically different)				

Table 6. Output data for chi-square test, WM 75 steel vs. aluminum car data.

The P-value for the chi-square test is well below 0.05, therefore there is a statistically significant difference between the steel and aluminum car groups. The majority of variation in the chi-square total comes from the shelled wheels on both car types. Note that the aluminum cars are performing much worse than expected (374 actual vs. 283.08 expected) for shelled wheels, while the steel cars are performing much better than expected (74 actual vs. 164.92 expected).

FLEET DATA - OTHER WHY MADE CODES

Chi-square analyses were then performed for wear-related why made codes (Why Made 60, 64 and 73) to see if the aluminum cars were performing better or worse than the steel cars with respect to these wheel removals. The analysis showed that there was no statistically significant difference in the performance of steel and aluminum cars for Why Made Codes 60 (Flange thin, P-value = 0.307) and 73 (Rim thin, P-value 0.855). The two groups of cars are performing the same with respect to these two Why Made Codes. However, the aluminum cars were found to be performing better than the steel cars for Why Made Code 64 (Flange high, P-value = 0.000). Results for the Why Made Code 64 chi-square test are shown in Table 7.

Car Type		Other Why Made Code Removals "Good"	Why Made Code 64 Removals "Bad"	Total Wheel Removals
Aluminum	Actual	1287	560	1847
	Expected	1225.86	621.14	
Steel	Actual	653	423	1076
	Expected	714.14	361.86	
Chi-sq. = 3.050 + 6.019 + 5.235 + 10.331 = 24.635				
Degrees of Freedom = 1, P-value = 0.000 (thus samples are statistically different)				

Table 7. Chi-square actual and expected values of WM Code 64 wheel removals.

COMPARISON TO AAR CRB WHEEL REMOVAL DATA

AAR CRB data from years 1999 and 2000 are contained in two papers published by the Railway Wheel Manufacturers' Engineering Committee (RWMEC) (Ref. 3, 4). AAR CRB wheel removal data do not contain all wheel removals since home line repairs and most private car shop wheel changeouts are not included, but are a large sample that can be used for comparison purposes. Also, AAR CRB data contain wheel removals for a wide variety of car types and cars that operate at different gross rail loads. Selected CRB wheel removal data for 1999 and 2000 are shown in Table 8, along with removals for the Utility's cars. Note that the Why Made Code 25 removals are not included in Table 8.

AAR Why Made Code	Number Of Wheel Removals			
	1999 AAR CRB Data	2000 AAR CRB Data	Utility Steel Cars	Utility Aluminum Cars
11	190,128	187,811	488	751
60	22,128	22,774	20	45
64	53,464	55,664	423	560
73	12,431	14,672	7	11
75	80,298	53,060	74	374
78	27,018	25,564	0	2
90	86,058	71,537	63	49
98	11,405	9,360	0	2
Total Removals	**516,567**	**470,618**	**1,076**	**1,847**

Table 8. Why Made Code data for AAR CRB 1999, 2000 and the Utility.

The chi-square statistical test was again used to analyze wheel shelling data. This time it was used to determine if the Utility's steel and aluminum fleets are different from the AAR CRB data. Minitab® statistical software was used for the calculations. The steel car group's shelling removals were found to be statistically significantly different than both the 1999 and 2000 CRB data. The same was true for the aluminum cars. Results for these chi-square tests are shown in Table 9. P-values for all four chi-square analysis combinations (steel and 1999 CRB, steel and 2000 CRB, aluminum and 1999 CRB, aluminum and 2000 CRB) were all 0.000, thus less than 0.05 and indicating statistical significance. Also, the majority of chi-square total variation was due to the number of shelled wheels for each of the four cases.

Utility Car Type		Chi-square results vs. 1999 CRB Data	Chi-square results vs. 2000 CRB Data
Aluminum	Actual	374	374
	Expected	287.42	208.89
Steel	Actual	74	74
	Expected	166.95	121.31

Table 9. Chi-square actual and expected values of WM Code 75 wheel removals.

Note that the expected number of shelling wheel removals for steel cars is above the actual number. This means that the steel cars are performing better in service with regard to wheel shelling than the overall AAR CRB samples. However, the reverse is true for aluminum cars. The aluminum coal cars are performing worse in service with regard to wheel shelling than AAR CRB data.

CONCLUDING REMARKS

The major differences between the steel and aluminum cars appear to be: 1) gross rail load level, 2) truck vs. foundation brake systems, 3) type of empty load device, 4) empty weight/braking ratio of equipment. Other variables, such as mileage, seem to be the same for the two car types. The aluminum cars are performing better than the steel cars with respect to wheel wear (Why Made Code 64, flange high). It is unknown if the difference in wheel shelling performance (worse for the aluminum cars than for the steel cars) is due to greater wheel sliding on lighter equipment or the heavier load experienced by the aluminum cars. However, it is clear that the shelling performance of the aluminum cars operated at 286,000 pounds GRL is inferior to the steel cars operated at 270,000 pounds GRL, and to the AAR CRB population of all cars. These data suggest that 286K GRL is indeed more damaging to wheels, or perhaps the lighter cars are sliding more often when empty.

It is likely that the fleet of cars operated by the Utility is not a representative sample when compared to all North American cars. The Utility arguably maintains its cars to a higher standard and uses premium components. The low incidence of such Why Made Codes as 76 and 78, along with an absence of wheel failures, suggests that maintenance procedures are keeping ahead of major wheel and brake system problems. However, the author believes that the Utility's fleet is roughly comparable to those of other coal car fleets in use in North America.

RECOMMENDATIONS

The effects of higher gross rail load on wheel performance should be a continuing area of study for the railroad industry. Analysis of wheel removal data from additional fleets of coal cars (and perhaps other cars in heavy axle load service) will provide additional information. Before gross rail loads are further increased from 286,000 pounds GRL to, for example, 315,000 pounds GRL, cost-benefit and risk studies should be performed to quantify maintenance cost and revenue-related benefits associated with heavy axle load operations.

REFERENCES

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