Optimizing the Maintenance Program for Rio Tinto Iron Ore's Train Wheels

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Abstract

This project was initiated to provide input into a review of Rio Tinto Iron Ore's ore car wheel set maintenance tactics. The project has collated data from trackside and maintenance equipment to examine the wear rates of wheels, the time to first repair and mean time between repair. From the initial sample of 20 wheel sets it has been found that the majority of repairs occur well inside the 2 year planned period. In addition the project has identified a number of issues with the way data is stored and recorded and aims to validate the accuracy of some of the data sources.

1. Rio Tinto Ore Cars

Rio Tinto has a fleet of 4500 ore car pairs that move Rio Tinto's iron ore through 1400 kilometres of rail from its Pilbara mines to ports in Dampier and Cape Lambert. Each ore car pair has four bogies and eight wheel sets. There is a significant investment in the maintenance of wheels, bearings and drawgear on each ore car with the majority of maintenance conducted at the 7 Mile rail facility outside Karratha.

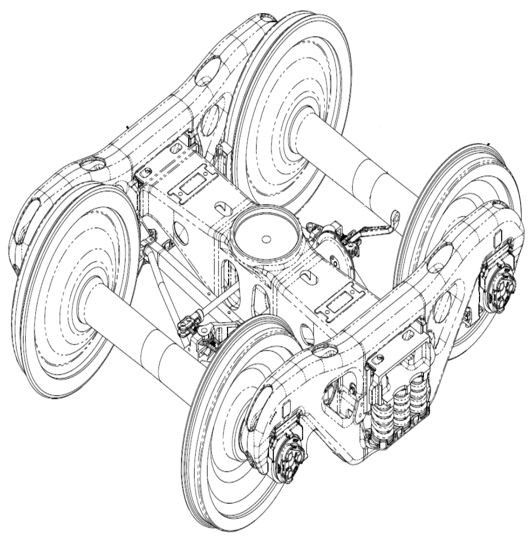

Figure 1: S Class Bogie

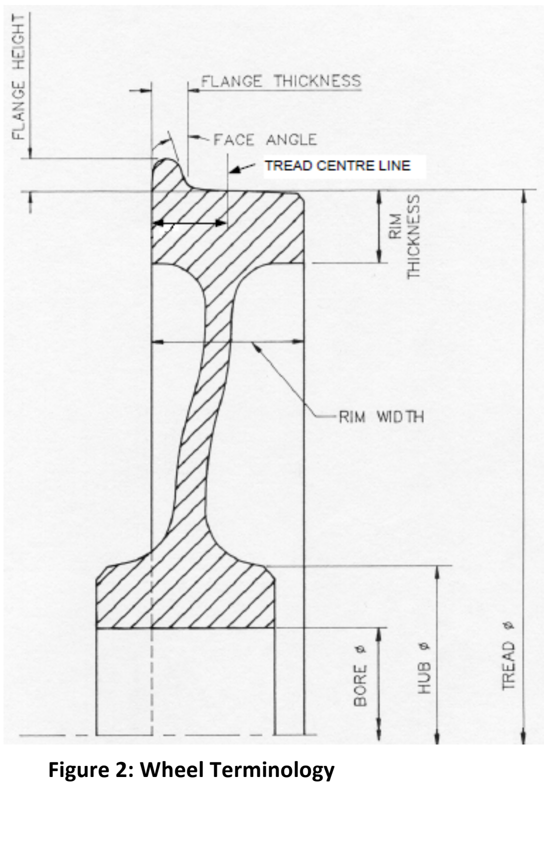

Figure 2: Wheel Terminology

Wheel sets consist of two wheels pressed onto an axle. Bearings are then attached to the end of the axle outside the wheels. The bogie then sits on top of the bearings (see Figure 1(Bradken Resources, 2008)). As the wagons move along the rail, the surface of the wheel is subjected to thermal and fatigue cracking, flats, shelled or grooved tread and flat or chipped areas. The profile of the wheel can also wear out of shape, creating higher wear rates and in extreme cases causing the train to derail. Many of these defects can be machined out using a wheel lathe. When a defect is detected (or the wheels reach a planned maintenance interval) the ore car is shunted to the Karratha facility and lifted off its wheels by a large multi-arm jack. New wheels are placed under the wagon and the wagon is returned to service. Meanwhile the old wheels are inspected for wheel, axle and bearing defects. After inspection the wheel lathe is used to cut the wheels down to a smaller diameter so that fresh, undamaged material is exposed and the profile is returned to its original shape. The depth of cut depends on the degree of damage found in the inspection. Rio Tinto has a standard set of rules for the cut. In some cases the operator’s discretion is required when machining sub surface defects or when rough machining is caused by the cutting tool having to remove a large volume of material at a certain point on the wheel. After being run through the lathe the wheel sets are then matched to other sets of similar diameter and put back on to another wagon.

Currently the wheel sets are bought in for machining on a two year planned maintenance period. The project was created to assess if the two year maintenance plan was still optimal. Interviews with Perth and site based engineers indicate a widely varied understanding of the purpose behind the current two-year scheme. There are over 36000 wheel sets in the network and the maintenance program represent a significant direct cost in labour and materials as well as costs in train delays and track damage from damaged wheels.

1.1 Literature review

Although there have undoubtedly been similar broad scale studies of trackside equipment data privately, there is a limited amount publically available. An in depth statistical study was conducted on wheel sets from a Brazilian company (Freitas et al., 2009). The study examined a small sample of 14 wheel sets of which only three had reached the end of their life. While the statistics were quite robust, this is a relatively small sample to draw conclusions from. A broad review of the available trackside monitoring systems has also been conducted in past studies (Lagnebäck, 2007). Rio Tinto operates almost all of the trackside equipment the Lagnebäck study reviews, apart from hunting detection systems.

Previous studies have created a predictive model for wheel set wear based on laboratory conditions (Braghin et al., 2006, Zobory, 1997). While Braghin’s predictive model couldn’t predict the wear on wheels in service accurately, it was within 5% accuracy for laboratory conditions. In addition they managed to use empirical data to identify an optimal machining interval using flange wear rates for an Italian passenger train.

1.3 Method

The focus of the project is to review the relevant wheel set databases. This data is sourced from computer numeric controlled (CNC) machinery, as well as the System Applications Product (SAP) software. The project will analyse the data to provide input into developing new maintenance tactics for the wheel sets. The project samples data for a set of wheels from the different trackside and CNC systems. From that the sample time to first repair and mean time between repair distributions can be created for the different brands of wheel sets and types of ore cars. From this information a reliability analysis of the failure profiles can be conducted for a number of the failure modes. In addition there is an opportunity to compare wagon and wheel brand combinations for risk factors of certain failure modes; however a predictive model is unlikely to be supported by the level of data available at this point.

2. Process

After identifying the possible information sources and downloading the data from the CNC machinery and trackside equipment, Excel macros were written to collate the data. The wheel lathe produced in excess of 24 000 text files that were automatically collated into a single database. The most complex of the programs extracts the laser profile data for the wheel sets. The program references multiple databases to retrieve wheel location information and magnetic tag numbers for a user selected list of wheels. It then searches the laser profile database for the identified wagons between the identified dates and collects all the readings into a new Excel file for each wheel set. The program searches up to 30 gigabytes of .csv (comma separated value) files to find the applicable data for each wheel set.

SAP wheel change dates are often out by up to a week from the actual time that a wheel change is seen in the laser profile reader. This meant that the program also had to search a small distance either side of the change date and decide when the wheel was actually changed. A wheel change is usually signified by a step change in wheel tread thickness (shown in Figure 2 (RailCorp, 2013) as “rim thickness”). Hence by comparing wear rates from a small, manually cleaned sample it is possible to identify when the wheel sets were changed. Once the possible change points are identified the thickness of the tread is compared either side of the change point to determine if the high wear rates were caused by a bad reading or due to an actual wheel set change. The data that doesn’t apply to the change is then deleted. If no change can be identified as the tread thickness of the new wheel closely matches the old wheel, the SAP dates are assumed correct. Once this process is completed the file contains a history of all the laser readings for that wheel across all the wagons it has been on. Wheel diameters can then be verified for some data points by using the wheel lathe and wheel press data.

After verification the data can be explored using a number of statistical methods. Histograms of time to first failure and mean time between failures will be created for the sample population. The population will then be filtered by wagon type and wheel brand to assess if there is a significant difference in the distribution of failure times. The distribution of the useful life of the wheels will then be created as an input into wheel ordering decisions.

2.1 Data Sources

Laser profile readers are used to measure the profile and diameter of train wheel sets while the trains are operating on track. The system consists of a detector that switches on the system and opens protective shutters as the train approaches. A magnetic Automatic Car Identification (ACI) tag is then read to identify each ore car. As each wheel approaches the laser, readings for each wheel position are paired with the ore car ACI number. The laser projects a line across the surface of the wheel and a black and white digital camera takes a photo of the wheel. The photo has a very high contrast to produce a black image with a white line created by the laser. The profile of the wheel can be calculated for a single point on the circumference since the location of the wheel, laser and camera are all known.

There are a number of issues working with data from a laser profile reader. The system requires a contrast between the laser and the wheel to produce a reading. Under some light and dust conditions, incorrect readings may be produced. As the laser profile reader reads a single line across the surface of the wheel, localized damage can also corrupt the readings. A portion of the system anomalies are caught by the laser profile system and labelled with a reason why the bad reading occurred. The more difficult challenge is the system's inability to record the actual wheel set number, only recording the wagon number and its position. This means that the data can only be searched by wagon number which only gives a partial snapshot of the wheels life. To piece together the entire wheel life the laser profile system data has to be matched with data in the SAP system.

The SAP software has a large variety of uses throughout Rio Tinto. From the maintenance viewpoint it tracks assets such as an ore wagon, the major parts allocated to that asset and the maintenance performed on the asset or its parts. It also tracks information such as purchase orders. In the context of this project there are several important aspects that the SAP system tracks. The first is which wagon a wheel set is on at any given time. Since the wheels normally switch wagon every time they are machined a single wheel set moves between multiple wagons throughout its life. Matching wheels to wagons is important to match the laser profile readings to an actual wheel set so that a complete history of readings can be formed.

There are two CNC machines currently used in the maintenance of wheel sets. The first is the wheel press which is used to press new wheels onto the axle, which has a longer useful life than the wheels. The operator keys in the date and time, the new wheel brand, the manufacturing date of the wheel, and the wheel press records this information along with the pressures used to press the wheels onto the axle. This provides a data source to work out when wheels where pressed onto the axle and what brand they were. In contrast the SAP system only shows which brand of wheel is currently on the wheel set and does not tell you when it was pressed on. The second machine is the wheel lathe which is used to cut the tread back below surface defects and to re-profile the tread. This produces a wheel diameter reading before and after cutting as well as back to back distances and wheel wobble. The wheel lathe has the shortest recorded data history of any of the systems (from 2011 onwards) so it will only be used for diameter verification for the laser profile system in this study.

3. Results

As the dataset is still being extracted, complete results are not yet available. However some experimentation with existing data has been undertaken. A typical set of tread wear readings from the laser profile reader can be seen in Figure 3 for part of the life of a wheel set. The tread thickness is calculated from the readings given by the laser profile system. The "SAP Wheel Change" points mark when the maintenance history says the wheels came into the 7 Mile site to be machined and placed on a new wagon. The vertical lines are placed every 2 years to show when planned maintenance was meant to occur.

It can be seen from the last reading that the maintenance data doesn't always reflect the actual date the wheel was changed. The step changes near the first, second and fourth wheel changes show when the wheel has been machined due to a defect, removing a large quantity of tread in a short period. The third wheel change point doesn't show this step change. It may have been switched for inspection when the carriage came in for other damage and found to need little to no machining. If the wheel was only skimmed by the wheel lathe the change in tread thickness would be lost in the noise from the data. It may also show that there has been an error in the SAP maintenance records but a larger data sample is needed before estimates of the accuracy of the SAP records can be made.

In addition some wheels have blanks in the SAP maintenance data. This creates holes in the middle of the tread wear history. This makes it very difficult to see how much of the material that was lost in that period was due to wear and how much was due to machining. It can also be seen that there is quite a large degree of noise in the data and the occasional bad reading. From the data the time to first repair and mean time between repair can be calculated.

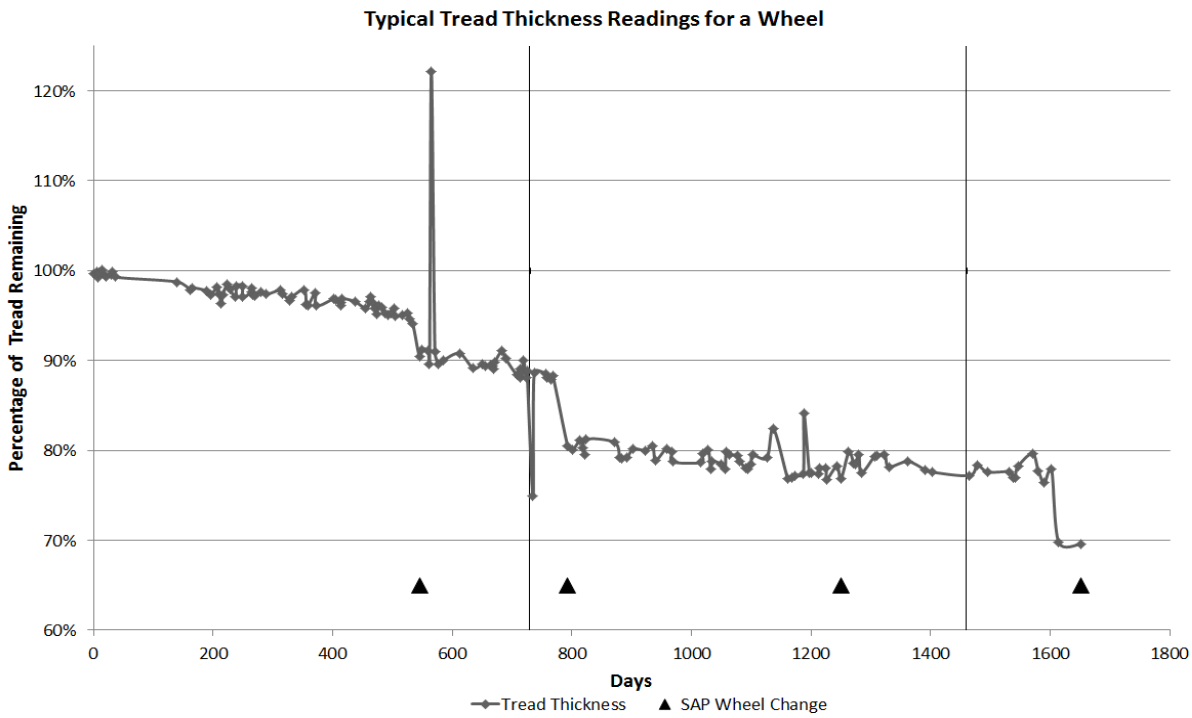

Figure 3: **Tread Thickness Readings**

4. Discussion

It is apparent from the initial examination of the data that the wheel is generally machined more frequently than the 730 days that corresponds to the 2 year planned maintenance period. This correlates with observations on site that most of the maintenance is done on condition from either the wayside track equipment or inspections when the wagon comes in for other maintenance. Some planned maintenance is conducted if a wagon does remain in the network for longer than 2 year but this does not seem to occur often from the initial sample.

There is no definite pattern between the depth of cut and the time between cuts for this data. It would be expected that certain failure modes such as cracking and flange wear would exhibit larger growth rates and wear rates as the wheel stayed in service longer. This increase in defect change rates has been found in other studies of wheel wear(Braghin et al., 2006, Peen, 2008). The likely reason for this is that there are a number of wheel failure modes such as flats that occur reasonably randomly. This can disguise any patterns in the failure mode. It may be possible to see some patterns when the maintenance data of why the wheel is cut back is matched against the laser profile data.

5. Conclusions and Future Work

At the time of writing the sample data set has not finished running through the data extraction program. As such the full statistical analysis is not yet complete and current results are based on a small initial sample of wheel sets. However this will represent the first time that a large sample of wheel wear histories are available in a single database. Previously only small sections of the wheels life could be viewed at a time as the data was matched to the car number. It is expected that in addition to the failure distributions of the wheel sets, the project will deliver a number of recommendations on future work and the way data is collected, stored and used. An example is that the SAP system is centred around maintenance work and as such when some assets end their life they are deleted out of the system. This missing data makes it difficult to review histories for certain assets.

A number of other studies need to be undertaken to give all inputs required for the maintenance tactics. The trackside equipment doesn't provide a history of subsurface defects. It has been shown that higher axle loads will increase the impact of subsurface rolling contact fatigue (Ekberg et al., 2007). As these cracks can't be detected by trackside equipment condition based maintenance is not practical. There is a need for further investigation into the rates of subsurface crack growth.

Another area identified for future study is flange wear. While this study uses the laser profile reader, it only uses numerical outputs. In the case of the flange thickness, the reference point used to measure the thickness moves relative to the hollowness of the tread. This stops a traditional wear rate review of the flange thickness being practical as different parts of the wheel are measured at different times through the wheels life. Instead, image processing software would be required to track the change in flange shape and understand the wear. The wheel set tracking issues addressed in this study will also be relevant when addressing flange wear. Finally the outputs from this project and future work will need to be matched against business costing to form a final decision on the maintenance tactics.

6. References

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