

# Conveyor Belt Wear Life Modelling

Callum Webb

Professor Melinda Hodkiewicz  
School of Mechanical and Chemical Engineering

Assistant Professor Nazim Khan  
School of Mathematics and Statistics

Stephen Muller, Rick Wilson  
BHP Billiton Iron Ore

## Abstract

*BHP Billiton Iron Ore (the client) owns and operates over three hundred conveyor systems with a total length exceeding two hundred kilometres across its operations in the Pilbara region. The current approach to estimating remaining life of conveyor belts is based on extrapolating thickness worn per unit of time. This has several limitations, such as failing to consider changes in conveyor utilisation or downtime. Five alternative measures of wear rate for conveyor belts have been formulated and investigated. Analysis of data from 114 belts installed on 22 different conveyor systems has shown that these alternatives provide better support for predicting remaining belt life compared to the traditional approach. In particular, throughput based wear rates produce models with greater explanatory power and capture changes in conveyor utilisation and downtime. Predictive models based on all six wear definitions have been developed using multiple linear regression, providing tools for forecasting belt replacements based on conveyor design and operational parameters.*

## 1. Introduction

Currently, the client's approach to planning belt maintenance is based on historical belt replacement data and staff experience. The client wishes to reduce the risks inherent in this process by developing an evidence based understanding of the factors that influence belt wear, and a tested approach to planning replacement. Conveyor belt thickness measurements are conducted periodically as part of routine inspections and maintenance. While this raw data provides trends to estimate remaining life, it has several limitations:

- Utilisation in terms of conveyor throughput and running time is not taken into account, compromising the accuracy of predictions.
- The data currently considered are not sufficient to allow for accurate and confident forecasting of replacements.
- Wear rates can only be estimated as thickness data becomes available.
- Belt life on similar, new installations cannot be predicted.

The aim of this project is to develop a data-based tool for predicting remaining belt life, and a better understanding of the factors that affect the rate of conveyor belt wear. Multiple regression techniques similar to those used by Badisch, Ilo and Polak (2009) and Krishnaswamy and Krishnan (2002) were used to develop predictive models.

## 2. Methodology

### 2.1 Data Collection

A review of literature (Goldbeck, Tech Assoc & Paper 1997), (Scherbakov & Shi 2004) and (Swinderman 2010), followed by brainstorming sessions and consultation with experienced personnel developed a set of candidate variables to consider for analysis. Assessment of available data narrowed this set down to a selection of variables that can feasibly be obtained. The four main sources of data are summarised in Table 1. “Belt Specifications” encompasses a range of miscellaneous data sources. Product drop height data was obtained for a subset of the data considered, and formed a separate smaller study. Results presented in this conference paper do not include this variable.

Belt Condition Monitoring	Material Tracking	Belt Specifications	Technical Drawings
<ul style="list-style-type: none"> <li>• Thickness test results</li> <li>• Belt material grade</li> <li>• Belt strength</li> <li>• Belt width</li> </ul>	<ul style="list-style-type: none"> <li>• Throughput</li> <li>• Product type</li> <li>• Running time</li> </ul>	<ul style="list-style-type: none"> <li>• Belt length</li> <li>• Belt speed</li> <li>• Conveyor type</li> </ul>	<ul style="list-style-type: none"> <li>• Product drop height</li> </ul>

**Table 1** Data sources.

### 2.2 Conveyor Belt Short-Listing

A subset of the client’s conveyor systems has been considered for analysis. To support an initial exploration of data, a short-list of twelve conveyor systems was developed. Conveyors were grouped by duty type (ship loader, stacker, reclaimer etc.), and ranked in order of change out frequency. By considering a number of high use conveyors for which data were available from each group, an adequate spread of the variables to be investigated was captured in this short-list. After techniques were tested and refined, this task was revisited and the short-list extended to twenty two conveyors.

### 2.3 Quantifying Wear Rate

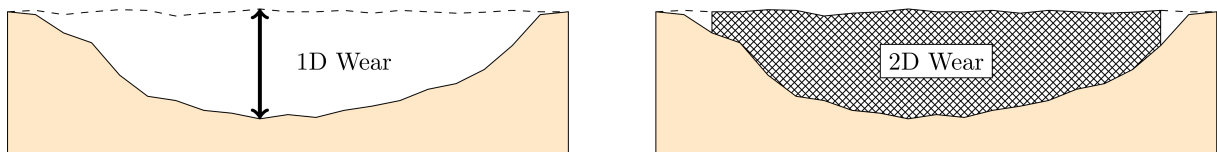
To facilitate further analysis and development of predictive tools, the rate of conveyor belt wear needs to be quantified consistently. Current industry practice is to assume wear is linear with time, and then select the position on the belt that appears to be wearing out most rapidly. This produces a value for wear rate in millimetres per unit of time.

This approach is limited for predicting belt life in that it does not necessarily take into account conveyor throughput, or fully describe the change in belt cross-sectional area. To explore potential improvement on current practices, five alternative methods for quantifying wear rate were formulated, and these along with the current method are summarised in Table 2.

1D time based wear corresponds to the current industry approach. 2D wear is calculated by considering all load-bearing test locations across the width of the belt and summing the total cross-sectional area removed. 3D wear is equal to the product of 2D wear and belt length. Wear rates based on throughput captures conveyor downtime and utilisation by replacing the denominator of time with millions of tonnes. 1D and 2D wear are illustrated in Figure 1.

Wear Rate Quantity			
	1-Dimensional (1D)	2-Dimensional (2D)	3-Dimensional (3D)
Time Based	$\frac{mm}{Week}$	$\frac{mm^2}{Week}$	$\frac{m^3}{Week}$
Throughput Based	$\frac{mm}{MT}$	$\frac{mm^2}{MT}$	$\frac{m^3}{MT}$

**Table 2** Wear rate quantification schemes. Traditional scheme highlighted.



**Figure 1** Belt cross-section, visualising 1D and 2D wear.

### 3. Results and Discussion

#### 3.1 Exploratory Data Analysis

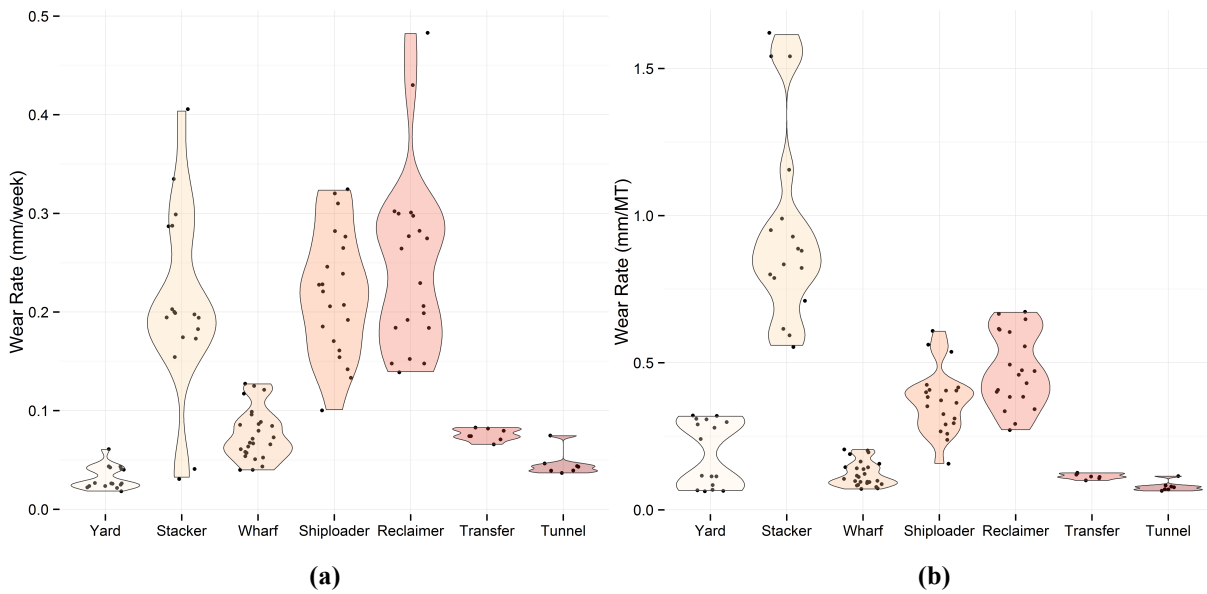
The distributions of wear rates across conveyor duties were studied for all six wear rate measures. The results of both 1D time and throughput based wear rates are shown in Figure 2. It can be seen that shorter, lower cycle time belts such as stackers, ship loaders and reclaimers tend to wear out more rapidly than their longer counterparts. This is true for both time based and throughput based wear rates.

When switching from time based to throughput based wear, stacker belts display increased wear rate and separate from the other groups. Other predictor variables, such as belt length, width, speed, and cycle time are relatively similar for stackers, reclaimers and ship loaders, and are therefore unlikely to account for this difference. This indicates that conveyor duty is an important variable for explaining variation in mean wear rate.

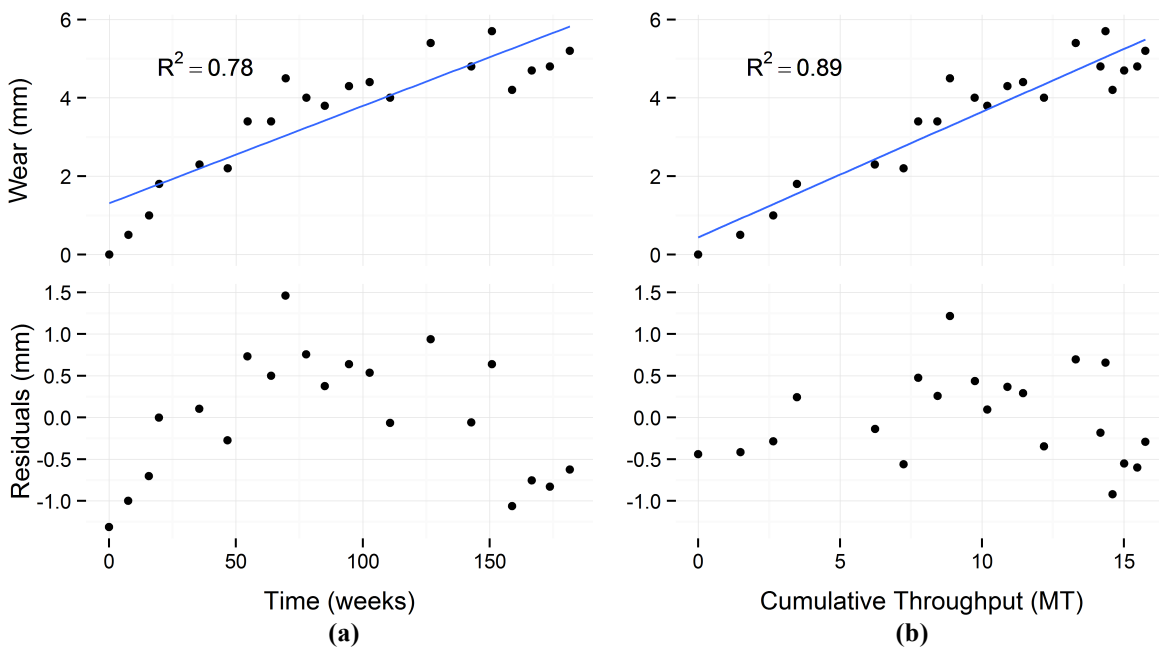
#### 3.2 Quantifying Wear Rate

The implications of defining wear as either the traditional 1D time based estimate or one of the five proposed alternatives was studied. Firstly, it was found that the rate of wear for the majority of data records was relatively constant throughout the life of the belt. Some exceptions were noted where changes in conveyor throughput resulted in non-linear wear with time. For these records, it was observed that describing the same wear pattern using a throughput based definition of wear rate produced a more linear relationship.

An example is shown in Figure 3, where the same data record is described using the traditional 1D time based definition, and a 1D throughput based definition. The greater correlation coefficient (0.89 vs. 0.78) and less patterned residual plot indicate that the throughput based approach is a simpler and more accurate description of the life-time wear rate.



**Figure 2** Distribution of 1D time based (a) and throughput based (b) wear rates across conveyor duties.

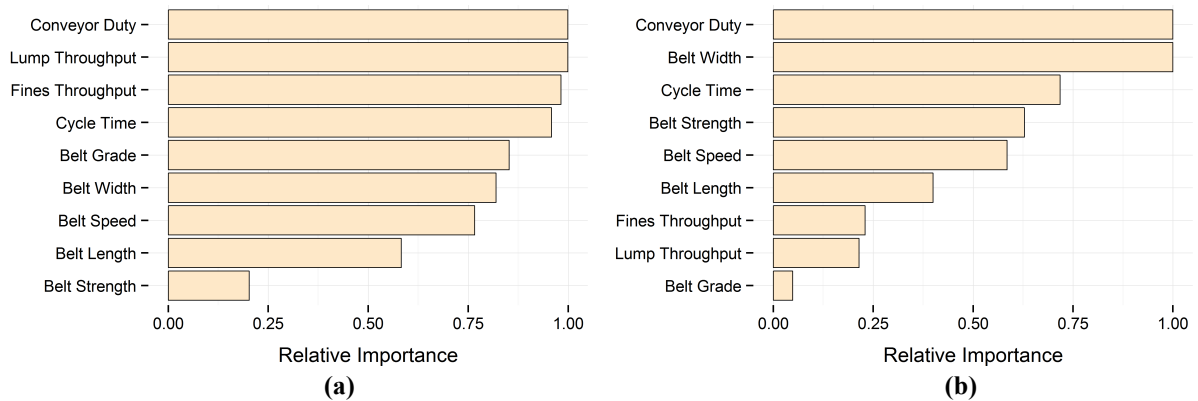


**Figure 3** 1D wear of a single conveyor belt with time (a) and throughput (b).

### 3.3 Model Selection

For all six different wear measures, the set of candidate models was searched exhaustively. Models were compared using the Akaike information criterion, corrected for finite sample sizes (AICc). This criterion ranks models by rewarding goodness of fit, and penalising model complexity (Hurvich & Tsai 1991). Interactions between predictors were ignored, resulting in 512 possible models. The best 100 were analysed to assess which predictor variables appear to be most important. Predictor relative importance was calculated by taking the weighted sum of the number of models that the variable appears in (weighted by relative AICc). Figure 4 shows the results of this analysis for 1D time wear and 1D throughput wear models.

It can be seen that conveyor duty and cycle time are important variables, appearing in almost all of the best 100 models for each of the two wear rate measures. The importance of conveyor throughput decreases when moving from time to throughput based wear.



**Figure 4** Relative importance of predictor variables for 1D time based (a) and throughput (b) wear models.

### 3.4 Predictive Tools

The values of the adjusted coefficient of determination ( $\bar{R}^2$ ) for the best model of each wear rate measure according to the AICc are shown in table 3. A model that perfectly explains wear rate would have an  $\bar{R}^2$  value of exactly one.

$\bar{R}^2$  is observed to increase when using a throughput based measure for each dimension of wear rate, and also increases with the number of dimensions. These results show that although the traditional approach to quantifying wear rate produces a model with some explanatory power, the alternative approaches produce models that better explain wear rate variation for the data considered.

Values of $\bar{R}^2$ for best models			
	1D	2D	3D
Time Based	0.783	0.818	0.876
Throughput Based	0.830	0.853	0.953

**Table 3** Adjusted coefficient of determination of the best model using each wear rate measure. Traditional measure highlighted.

1D wear rates are more immediately accessible for predicting useful belt life, as no knowledge of the distribution of wear is required. The best 1D throughput based wear rate model includes conveyor duty, belt width, strength, speed, and cycle time as predictor variables and is shown below. By substituting values for  $X$  which describe a particular conveyor belt, the remaining useful life in terms of throughput can be estimated.

$$\left[ \frac{mm}{MT} \right] = -0.285 - 0.221 \cdot X_{duty\ 1} + 0.659 \cdot X_{duty\ 2} - 0.310 \cdot X_{duty\ 3} + 0.185 \cdot X_{duty\ 4} + 0.323 \cdot X_{duty\ 5} - 0.187 \cdot X_{duty\ 6} - 0.121 \cdot X_{width\ 1} + 0.288 \cdot X_{width\ 2} + 0.042 \cdot X_{strength\ 1} - 0.283 \cdot X_{strength\ 2} + 0.076 \cdot X_{strength\ 3} + 0.119 \cdot X_{speed} + 0.0005 \cdot X_{cycle\ time}$$

## 4. Conclusions and Future Work

Current industry practice for wear rate measurement has been compared with five alternatives. By analysing data of 114 belt histories on 22 separate conveyor systems, several advantages of throughput based wear quantification schemes over the traditional time based approach have been identified. These include: capturing conveyor downtime and changes in throughput rate, increased wear linearity over belt life, and better support for predictive models.

Wear rate models have been developed using linear multiple regression techniques, providing both a tool for predicting conveyor belt life as well as insights into the effects of variables. Models for 2D and 3D wear show higher adjusted coefficients of determination, indicating higher explanatory power. More work in the area of model verification, such as through cross validation should be carried out to establish the predictive capability of these models. Further investigation into modelling the distribution of wear across the belt cross section may also make 2D and 3D approaches more practical for predicting belt life.

Interactions between predictor variables have not yet been considered. Including these terms in modelling causes the set of candidate models to greatly expand in size, but may also produce a better predictive model. More work in quantifying design aspects of conveyors, such as loading point design, product density and relative impact velocity may improve model generalizability.

## 6. References

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