

OPTIMIZATION OF WHEEL-RAIL PROFILE COMBINATIONS IN TERMS OF ACCURATE WEAR PREDICTION

Koci Doraci, Alfred Hasanaj*

University Polytechnic of Tirana, Tirana, Albania

Abstract. Predicting, calculating and minimizing rail profile-wheel wear is still an important inquiry, despite the evolution in its formulation. This paper will contribute to solving the wear prediction problem, frameworked by the guidelines given below: (a) Wear minimization in terms of different curve radiuses and (2) Wear minimization in terms of different wheel-rail profile combinations. The objectives of the paper are: (1) To maximize prediction accuracy of the wear index (a) in terms of the overall wear index, (b) in terms of wheel-rail combinations and (c) in terms of curve radius; (2) To optimize wheel-rail profile combinations in terms of wear indices for different curve radius scenarios. Overall, the main contributions of the paper are: (1) this paper significantly contributes to solving one of the most important problems of wheel-rail contact optimization: prediction of wear indices in tight curved rail tracks; (2) this paper accesses the predicted value of the wear index in different curve radius scenarios, creating the possibility of adaptation in both ways – to adapt the rail profile to the wheel type and/ or to adapt the wheel type to the rail profile type.

Key words: Wear prediction, rail profile-wheel wear combination, curve, and optimization

DOI: 10.21175/RadProc.2017.61

1. INTRODUCTION

1.1. Problem Identification

It is declared in Pomboa et al. [1], Ignesti et al. [2] and Han et al. [3] that the decisive factors that establish train competitiveness as a means of transport compared to other alternative means of transport are wheel profiles and rail wear.

Therefore, the problem of predicting, calculating, and minimizing rail profile-wheel wear is still an important inquiry, despite the evolution in its formulation.

In [1] it is concluded that, nowadays, the problem of predicting wheel and rail wear has been overcome, and that the real problem which scholars confront is to generate increasingly realistic predicting models. This is additionally confirmed by several studies which have rejected results measured by traditional apparatuses used for decades for predicting rail and wheel wear (an example being [4]).

Another group of authors formulate wear prediction in terms of the lack of proper apparatus for innovative technological developments. For example, a substantial lack is present in the literature concerning wear models specially developed for complex railway network applications [5].

This paper will contribute to solving the wear prediction problem, within a framework defined by the guidelines below:

- Wear minimization in terms of different curve radius
- Wear minimization in terms of different wheel-rail profile combinations

1.2. Paper objectives

Given the above definition of the problem, the paper's objectives are:

- (1) To maximize the prediction accuracy of the wear index (a) in terms of the overall wear index, (b) in terms of wheel-rail combinations and (c) in terms of the curve radius.
- (2) To optimize wheel-rail profile combinations in terms of wear indices for different curve radius scenarios.

1.3. Literature review

This section presents different works that have addressed the problem of predicting wear in rail profiles and/or wheels.

This decade saw the publication of several innovative works that have changed the traditional approach toward this problem.

* alfred.hasanaj@yahoo.com

Innovations presented by Innocenti et al. [5] are (1) the conduction of experiments not only in linear paths, but also in contexts that present difficulties and have the tendency to increase the rhythm of wear evolution, (2) transferring previous knowledge regarding wear prediction on current technological railway conditions, they specify how to analyze complex railway lines (3) the development of a new statistical approach contrary to conventional simulations and an experimental approach² for the railways.

Hossein et al. [6] have published a paper which addresses the prediction of wear for distances longer than 40,000 km.

A. Zmitrowicz [7] states that the majority of wear index prediction equations are a derivative of the Archard law and equations of wear in the framework of train movement. It can be concluded that the Archard equation³ is the most frequently used conventional way of predicting wear level.

An interesting study is “Simulation on wheel wear prediction of a high-speed train” by Luo et al. [4]. This paper compares wheel and profile wear prediction results deriving from the Archard model and a dynamic simulation in the context of high-speed trains. The paper concludes that the Archard model generates non-realistic values (greater than real wear).

It is referred in paper by I. Zoboroy [8] to the general tendency of predicting wheel and rail wear in recent years. According to him, contemporary wear prediction has been influenced by technological developments; therefore, the vast majority of prediction tools are in the form of algorithms, simulations, experiments, and numerical procedures. The author concludes that in spite of this evolution, the purpose of predicting procedures remains the same – to maximize the performance of train movement in terms of the vehicle system, railway line, wheel parameters, and a combination of these indicators.

This paper adds value to the current knowledge presented by the papers above in terms of presenting a new solution by predicting wear indices as a function of the rail profile-wheel combination. In this way, the methodology presented in these papers enables using a predictive apparatus for utility decisions regarding the optimization of wheel-rail profile combinations in different path scenarios.

2. METHODOLOGY

2.1. Calculation Methodology: The wear model

The wear is defined as being the total substance removed from rail and/ or wheel surfaces at their contact point, which is a consequence of train motion.

For the objectives of this paper, the formula used for predicting the wear index will be:

$$w = F_h \frac{V_h}{V} + F_v \frac{V_v}{V} + M \frac{\omega}{V} \quad (1)$$

where:

F_h – Horizontal creep force,

$\frac{V_h}{V}$ – Horizontal creepage,

F_v – Vertical creep force,

$\frac{V_v}{V}$ – Vertical creep age,

$\frac{\omega}{V}$ – Spin in the contact,

M – Moment of spin in the contact

According to this methodology, the wear rate is a function of all forces (horizontal and vertical) occurring during wheel-rail contact. Consequently, the wear level is dependent on the energy dissipation at the contact point.

2.2. Railway Track, Wheel and Rail Profile – wheel contact modeling

In this paper, Equation (1) will be implemented in several wheel and rail profile types and their combinations. Furthermore, track scenarios will be characterized by curves with a different radius.

This will enable the application of this equation for predicting wear in a variety of situations and for various optimizing decisions.

2.3. Variables and Data

The table below presents variables and data to be processed with formula (1).

Table 1. Research variables and data

Curve radius	Wheel Type	Rail profile Type	Wheel - Rail profile Combinations
300	WP4	BV50i30	WP4_BV50i30
600	S1002	MB1BV50	WP4_MB1BV50
900		UIC60i40	S1002_UIC60i40
1200		UIC60i20	S1002_UIC60i20
1500			

3. RESULTS AND INTERPRETATIONS

This section presents results derived from analyzing data in line with the methodology presented in the previous section.

Consistent with this paper’s objectives, the research results will be presented in two stages. The first stage will present results regarding the prediction accuracy of the methodological apparatus for wear prediction (as explained in the methodology section). The second stage presents results concerning the optimization of wheel-rail combinations for the four case studies included in this paper.

3.1. Prediction accuracy

Figure 1 and Table 2 present results which compare predicted and actual wear value for the WP4/BV50i30,

² Which according to the authors are methods that produce wear evaluation which turned out to be absolutely too high for each practical purpose.

³ It expresses wear volume in terms of normal load, sliding distance and surface hardness.

WP4/MB1BV50, S1002/ UIC60i40, S1002/ UIC60i20 wheel-rail combinations.

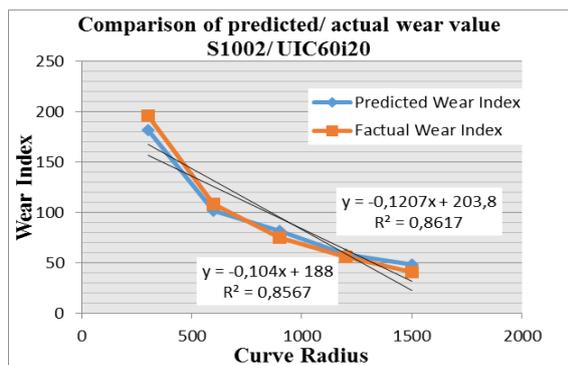
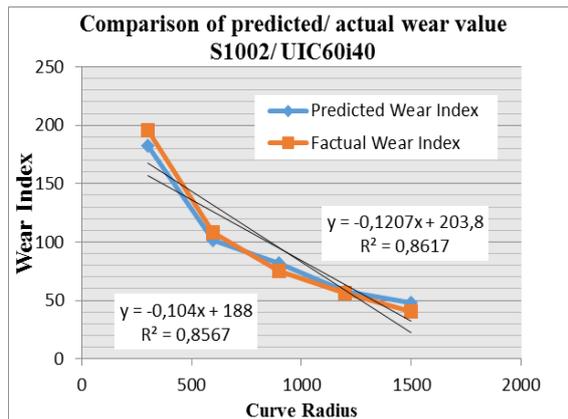
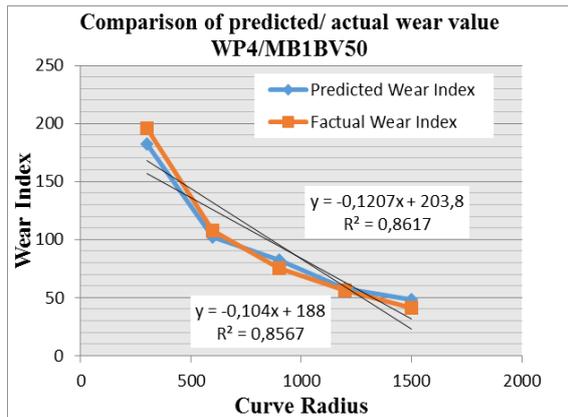
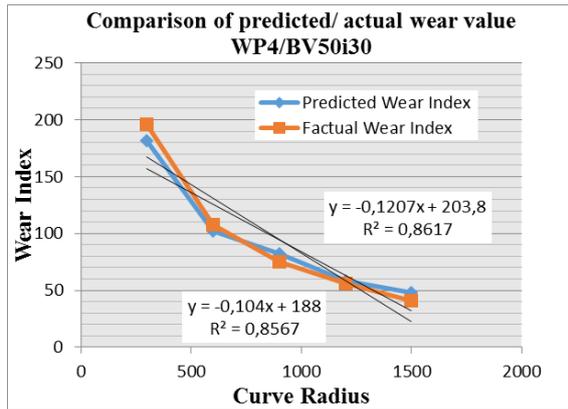


Figure 1. Comparison of predicted and actual wear value for different wheel-rail combination

Table 2. Comparison of predicted and actual wear value for different wheel-rail combinations

Curve radius	WP4/BV50i30			WP4/MB1BV50			S1002/UIC60i40			S1002/UIC60i20			Average Wear Prediction Accuracy
	Predicted Wear Index	Factual Wear Index	Wear Prediction Accuracy	Predicted Wear Index	Factual Wear Index	Wear Prediction Accuracy	Predicted Wear Index	Factual Wear Index	Wear Prediction Accuracy	Predicted Wear Index	Factual Wear Index	Wear Prediction Accuracy	
300	180	190	5,26%	182	196	7,14%	280	289	3,11%	900	891	-1,01%	3,63%
600	100	106	5,66%	102	108	5,56%	110	103	-6,80%	600	593	-1,18%	0,81%
900	80	85	5,88%	82	75	-9,33%	75	88	14,77%	500	550	9,09%	5,10%
1200	60	55	-9,09%	58	56	-3,57%	65	70	7,14%	400	385	-3,90%	-3,58%
1500	50	56	10,71%	48	41	-17,07%	55	76	27,63%	250	240	-4,17%	4,28%
Average Wear Prediction Accuracy			3,69%			-3,46%			9,17%			-0,23%	4,14%

Table 2 reports results concerning the overall wear prediction accuracy of the prediction apparatus used in this paper, as well as for each curve radius and for each of four wheel-rail combinations analyzed.

As may be verified, the overall wear prediction accuracy of the prediction apparatus designed for this paper is 4.14%. This means that, on average, Equation (1) presented in the methodology section produces wheel-rail wear indices 4.14% greater than factual wear indexes. This value may be considered satisfactory and is in convergence with the results of the other papers in terms of the direction of the prediction deviance. As [1] acknowledges, wear prediction instruments of current scholars generally have the tendency to report wear indices greater than actual ones. This occurs because they enable both the level of tolerance and of security.

Furthermore, the lowest deviation regarding wear prediction occurs for S1002/ UIC60i20, while the highest one occurs for S1002/ UIC60i40. This means that the wear prediction tool this paper suggests ensures safe values for S1002/ UIC60i40, and fluctuate, less accurate values for S1002/ UIC60i20. For WP4/BV50i30 and S1002/ UIC60i40, the wear prediction tool reports wear indexes greater than factual ones, while for WP4/MB1BV50 and S1002/ UIC60i20, the wear prediction tool reports wear indices lower than factual ones.

Lastly, regarding the curve radius, it can be concluded that (1) the higher the curve radius, the lower the wear index, and (2) the higher the curve radius, the lower the wear index prediction accuracy.

Firstly wear index minimization becomes more crucial with the decrease of the curve radius. Secondly, this paper is more accurate for tight curves, which is, of course, more useful given the first result. Therefore, this paper significantly contributes to solving one of the most important problems of the wheel-rail contact optimization: prediction of wear indices in tight curved rail tracks.

Table 2 results are completed by Figure 1. This figure presents comparisons of predicted and actual wear values for different wheel-rail combinations. As may be observed from the trend line results, the wear prediction tool of this paper reports generally higher wear indices than the real ones (expressed by steeper trend lines) and high accuracy (expressed by high values of r2).

3.2. Optimization of wheel-rail combinations

After assessing the accuracy of the prediction tool developed from this paper, it will be demonstrated how this tool can be used in order to optimize wheel-rail

contact (minimize wear index) by using different wheel-rail combinations.

This paper takes into account two types of wheels and two types of rail profiles, which produce four types of wheel-rail profile combinations.

The following table presents predicted wear indices of these four types of wheel-rail profile combinations.

Table 3. Wear indices of four types of wheel-rail profile combinations

	Wear Index				
	Wheel Type	WP4		S1002	
	Rail profile Type	BV50i30	MB1BV50	UIC60i40	UIC60i20
Curve radius	300	180	182	280	900
	600	100	102	110	600
	900	80	82	75	500
	1200	60	58	65	400
	1500	50	48	55	250

These results are graphically presented in Figure 2.

Fig. 2 enables us to assess that the most optimal wheel-rail profile combination in terms of a low wear index in curves with a different radius is the wp4_bv50mb1i30 combination. On the other hand, the most non-convenient wheel-rail profile combination is the S1002_UIC60i20 combination, due to a high wear index in curves with a different radius.

Given the above, in order to assess the most convenient wheel-rail profile, we should assess the predicted value of the wear index in different curve radius scenarios. This creates the possibility of adaptation in both ways –adapting the rail profile to the wheel type and/ or adapting the wheel type to rail profile type.

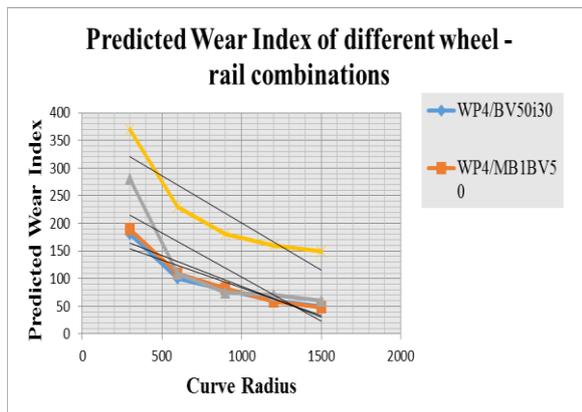


Figure 2. Wear indices of four types of wheel-rail profile combinations

4. CONCLUSIONS

The conclusions of this paper are focused in two major directions: (1) wear prediction accuracy and (2) optimization of wheel-rail combinations in terms of minimizing wear.

In detail, research results reveal: (1.a) the overall wear prediction accuracy of the prediction apparatus designed for this paper is 4.14%; (1.b) the lowest deviation of wear prediction for a certain rail profile-wheel combination is -0.23%, while the highest is 9.17%; (1.c) the higher the curve radius, the lower the wear index prediction accuracy; (2.a) the most optimal wheel-rail profile combination in terms of low wear index in curves with a different radius is the wp4_bv50mb1i30 combination. On the other hand, the most non-convenient wheel-rail profile combination is the S1002_UIC60i20 combination due to its high wear index in curves with different radius.

Overall, the main contributions of the paper are: (1) this paper significantly contributes to solving one of the most important problems of wheel-rail contact optimization – the prediction of wear indices in tight curved rail tracks; (2) this paper assesses the predicted value of the wear index in different curve radius scenarios, which creates the possibility of adaptation in both ways –adapting the rail profile to the wheel type and/or adapting the wheel type to rail profile type.

REFERENCES

1. J. Pomoboa, J. Ambrósioa, M. Pereiraa, R. Lewisb, R. D. Joyceb, C. Ariaudoc, "Development of a wear prediction tool for steel railway wheels using three alternative wear function," in *Proc. 8th Int. Conf. Contact Mechanics and Wear of Rail/Wheel Systems*, Florence, Italy, 2009, pp. 238 – 245.
DOI: 10.1016/j.wear.2010.10.072
2. M. Ignesti, L. Marini, E. Meli, A. Rindi, "Development of a Model for the Prediction of Wheel and Rail Wear in the Railway field," *J. comp. and nonlinear dyn.*, vol. 7, no. 4, pp. 041004-1 – 041004-14, Oct. 2012.
DOI: 10.1115/1.4006732
3. P. Han, W. H. Zhang, Y. Li, "Wear characteristics and prediction of wheel profiles in high-speed trains," *J. Centr. South Univ.*, vol. 22, no. 8, pp. 3232 – 3238, Aug. 2015.
DOI: 10.1007/s11771-015-2861-7
4. R. Luo, J. Zeng, "Simulation on wheel wear prediction of high-speed train," *Mocuaue Xuebao*, no. 6, pp. 551 – 558, 2009.
5. A. Innocenti, L. Marini, E. Meli, G. Pallini, A. Rindi, "Prediction of wheel and rail profile wear on complex railway nets," *Int. J. Rail Transportation*, vol. 2, no. 2, pp. 111 – 145, Apr. 2014.
DOI: 10.1080/23248378.2014.897792
6. S. Hossein, C. Casanueva, S. Stichel, "Prediction of RCF and wear evolution of iron-ore locomotive wheels," *Wear*, vol. 338-339, pp. 62 – 72, Sep. 2015.
DOI: 10.1016/j.wear.2015.05.015
7. A. Zmitrowicz, "Wear patterns and laws of wear: A review," *J. Theor. Appl. Phys.*, vol. 44, no. 2, pp. 219 – 253, Jan. 2006.
Retrieved from: <http://ptmts.org.pl/zmitr-2-06.pdf>
Retrieved on: Dec. 15, 2016
8. I. Zaboroy, "Prediction of wheel/rail profile wear," *Int. J. Vehicle Mech. Mob.*, vol. 28, no. 2-3, pp. 221 – 259, Jul. 2007.
DOI: 10.1080/00423119708969355