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Study on the service conditions that influence the wear evolution on railway wheels

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Abstract: In the past, the reprofiling intervals of railway vehicle steel wheels have been scheduled according to designers' experience. Today, more reliable and accurate tools in predicting wheel wear evolution and wheelset lifetime can be used in order to achieve economical and safety benefits. In this work, a computational tool that is able to predict the evolution of the wheel profiles for a given railway system, as a function of the distance run, is presented. The strategy adopted consists of using a commercial multibody software to study the railway dynamic problem and a purpose-built code for managing its pre and post-processing data in order to compute the wear. The tool is applied here to realistic operation scenarios in order to assess the effect of some service conditions on the wheel wear progression.

***Keywords**: Railway dynamics, Multibody systems, Wheel profile wear, Traction/braking forces.*

1 Introduction

The increase of the railway transport competitiveness requires the development of sophisticated railway systems that answer to the increasing demands of modern societies. For short and medium distances, high speed trains are able to compete with the air transportation, having several advantages such as better energy efficiency and less impact on the environment (e.g. CO_2 footprint). The increase of the railway share of persons and freight transport also relies on a more efficient transport system. In order to improve its competitiveness, railway industrial integrators and research centres are investing large resources in research and development activities. These studies contribute decisively to the development of new design concepts by using advanced simulation techniques, modern production methods and innovative optimization procedures.

One of the most sensible issues in the railway industry is the impact on infrastructure of train operations and the damage on vehicles provoked by the track conditions. These issues have a significant impact on the life cycle costs of the railway networks. The consequence is that the prices billed by the infrastructure managers to the railway operators are being defined according to the damage that the trainsets are supposed to cause to the track. Therefore, the study of vehicle-track interaction is important in reducing the operation and maintenance costs, by increasing the life cycle of both vehicles and tracks, and increasing the speed, safety and comfort indexes of the railway systems. In this regard, these studies have a significant role to play in promoting the competitiveness of the railway transportation.

During trainset operation, the wheels of railway vehicles are subjected to wear. When the worn state of the profiles reaches a limit value defined by international standards [1], the wheels have to be reprofiled. In the railway community it is well known that there are mission profiles (operation conditions, track geometry, wheel-rail profiles, etc.) where some trainsets require the reprofiling of their wheelsets after only 80.000 km of service, whereas others are able to operate in similar conditions for more than 400.000 km without need such maintenance procedure. Furthermore, the railway wheels can only be reprofiled 3 or 4 times and the wheelset substitution is very expensive. The excessive wheel wear implies that, conversely, also the rails are subjected to premature deterioration. Thus, the complete characterization of the wheel wear problem allows tackling the rail wear problem as well. It is, therefore, essential to acquire a better understanding on how the wheel wear evolution is affected by the mission profile of the trainsets and what is the impact of the wear growth on the dynamic behaviour of railway vehicles. Such evaluation is an important contribution to optimise the rolling stock design and to enhance the construction features of the railway infrastructure.

Up to now there are no commercial computational tools able to study, according to the trainset operation conditions, the wear evolution on railway wheels and to predict the intervals between the reprofiling procedures. The work presented here resulted from a Transfer of Knowledge (ToK) project between Industry and Academia, which aimed to contribute to the development of such a tool. The objective is to improve the modelling capabilities of the tools used to study the dynamic response of railway systems in order to enhance the wheel wear prediction techniques. This ToK project was called AWARE (ReliAble Prediction of the WeAr of Railway WhEels) and it was funded by the EU to meet its transport policy objectives for improvement of efficiency and competitiveness of the European railway transportation networks.

The capability of the computational tool for wheel wear prediction, developed in the scope of project AWARE, is demonstrated here in several realistic scenarios of operation. The purpose is to evaluate the influence on the wheel wear growth of some physical parameters related to the vehicle characteristics and to the trainset service conditions. Special emphasis is given to study how the wear progression is sensitive to the primary suspension stiffness, rail cant, rail profile, traction/braking forces and vehicle velocity. The assessment of the wear sensitivity to each one of these railway dynamic parameters is made in terms of predicted reprofiling intervals.

2 Overview of the wear prediction tool

The computational tool developed here to predict the wear of railway wheels consists of a commercial Multibody Software (MBS) to study the railway dynamic problem [2-4] and a purpose-built code for managing its pre and post-processing data in order to compute the wheel wear [5-13]. According to this strategy, an initial wheel profile is provided and the MBS runs a simulation for a pre-defined travel distance. Then, the wear prediction tool collects the necessary data from the dynamic analysis results and calculates the wear, i.e., the amount of material to be removed from the wheel surfaces. The resulting updated profiles are then used as input for a new dynamic analysis in the MBS. This methodology, represented in Figure 1, is repeated as many times as necessary until reaching the distance required for the wear study.

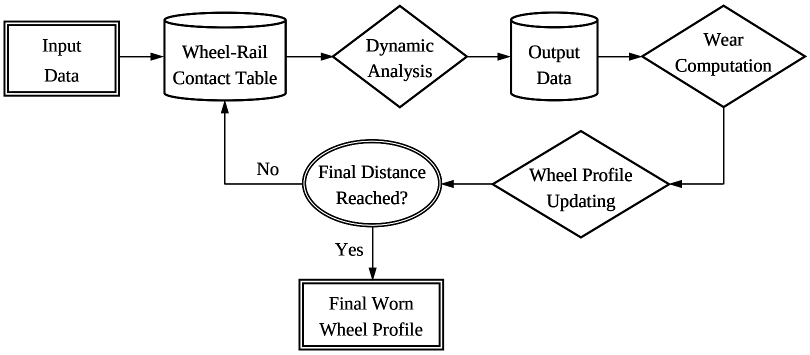


Figure 1: Schematic representation of the wear prediction tool

In real situations trainsets are operated on different tracks. Therefore, when predicting the wear evolution on the wheels of a railway vehicle, this issue has to be considered and the wear studies should be performed using track models (geometry and characteristics) that represent the real operation conditions. In the wear computational tool presented here, there are no limitations with respect to the length of the track models or to the number of models to use. In fact, after each simulation with the MBS, the wheel profiles are updated and used as input for a new dynamic analysis in the MBS. This new dynamic analysis can be performed with the same track model or with a different one. This approach allows computation of the wheel wear with more precision by reproducing the real conditions that the railway vehicles experience during their operation. The result is thus the wheel profile evolution, in respect of distance run, for the vehicle mission specified by the user.

A schematic representation of the wear computational tool is presented in Figure 1 and it consists of the following steps [7,10-13]: 1) Prepare the input data for the computation; 2) Obtain the wheel-rail contact table; 3) Run the multibody dynamic analysis; 4) Read the dynamic analysis output data; 5) Compute the quantity of worn material; 6) Update the wheel profiles. The wear prediction study ends when the total simulated distance matches the total distance defined by the user.

The wear computation block, represented in Figure 1, is the core of the wear prediction tool as it computes the amount of worn material to be removed from the wheel surfaces, starting from the MBS dynamic results. It is divided into 3 parts: i) Contact model; ii) Wear function; iii) Wear distribution. The contact model processes the dynamic analysis results to obtain the wheel-rail contact parameters [14-20]. The wear function uses these contact parameters as input to compute the quantity of worn wheel material [5,6,13,21-23]. The wear distribution allocates the quantity of worn material along the wheel profile.

The wear functions relate the energy dissipated in the wheel-rail contact patch with the amount of worn material to be removed. In general, these wear laws use the normal and tangential forces and the relative slip velocities (creepages), as input to compute the wear. In the literature [5,6,10-13,21-31] different methods for estimating wear of railway wheels can be found. These methods are based on real wear data acquired using different experimental techniques.

In this work, the wear function developed by the University of Sheffield [5,13,21-23] is used. It is based on twin disk experimental data acquired from the contact between discs made of R8T wheel material and UIC60 900A rail material. These experimental tests have identified three wear regimes, mild, severe and catastrophic [5-13], for the contact between wheel and rail materials. Notice that these materials are the ones used to assemble the vehicles and tracks considered here in performing the wear studies.

3 Wear parameters for steel railway wheels

During service, the steel wheels of railway vehicles are subjected to wear. These changes in the profile geometry affect the dynamic behaviour of the whole trainset and, consequently, their evolution has to be assessed. A common method for wheel wear geometric analysis is provided in the UIC 510-2 leaflet [1]. According to this standard, a good and pragmatic approach for the geometric characterisation of the wheels wear is based on the measurement of the profile parameters *Sh*, *Sd* and *qR*. These parameters are represented in Figure 2, where *Sh* is the flange height, *Sd* represents the flange thickness, *qR* is the flange slope quota, *D* is the wheel diameter, ΔD represents the deviation of roundness and d is the wheelset external gauge. The quantities L_1, L_2 and L_3 are the reference quotas for the measurement of the wheel wear parameters.

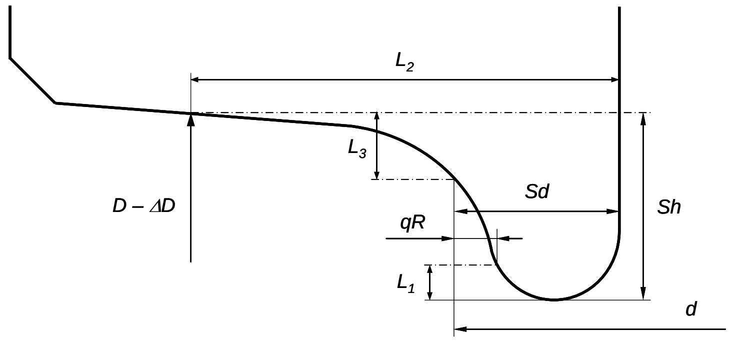


Figure 2: Wear parameters for railway steel wheels

The wheel wear characterization based on programmed measurements of the geometrical parameters *Sh*, *Sd* and *qR* is widely used by the railway industry. Such assessment is a relevant criterion to evaluate the wear state of the wheels. This approach consists of monitoring periodically the geometrical parameters of the wheel profiles in order to check if they have reached the safety limit values defined by the technical specifications. When that happens, it means that the wheels have to be reprofiled. According to the UIC 510-2 [1], the admissible values for parameters *Sh*, *Sd* and *qR* are defined in Table 1.

Table 1: Admissible values for wheel wear parameters

Wheel Profile S1002	Wear Parameters (mm) *Sh*	*Sd*	*qR*	Reference Quota (mm) L_1	L_2	L_3	Flange Angle
New Profile (mm) (760 < D < 1000)	28	32.5	10.8	2	70	10	70º
Allowable (mm) (840 < D < 1000)	≤ 36	≥ 22	> 6.5				–

The measurement of the wear parameters *Sd* and *qR* allows predicting the influence of the wear state of the wheel profiles on the dynamic behaviour of the railway vehicles. For example, the flange thickness *Sd* is very important as it limits the lateral clearance of wheelset with respect to the track, which influences the vehicle stability. The flange slope quota *qR* is also an important parameter. If it is too small, the wheel flange will be almost vertical, which implies that the transitions (switches crossing) and the flange contacts will occur abruptly. Such a situation originates very high contact forces that damage both vehicle and infrastructure. From Table 1 it is also noticeable that the difference between the new and the allowable values for the flange height *Sh* reveals that the maximum wear depth admissible in the wheel tread is 8 mm.

4 Wheel wear studies

In the following sections, several comparative studies are performed in order to evaluate the sensitivity of the wear evolution to some physical parameters related to the vehicle characteristics and to the trainset service conditions.

4.1 Influence of primary suspension stiffness

The trainset considered to study the influence on wear growth of the primary suspension stiffness is a three-vehicle articulated trainset with Jacobs's bogies represented in Figure 3. It is composed of four bogies, with the two bogies of the extremities being motorized (wheelsets are represented in black), and the two middle bogies being trailers (with wheelsets represented in white). Due to its configuration, the dynamic behaviour of each vehicle of the trainset affects the performance of the others. Therefore, the whole trainset has to be considered when building the vehicle model, which is used by the MBS to run the dynamic analyses during the wear studies. Hereafter it is named as Vehicle 1.

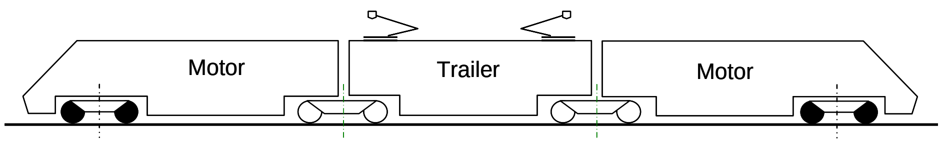


Figure 3: Vehicle 1 – Articulated trainset with Jacob's bogies

The 3D model of Vehicle 1 is built using a multibody approach [32-37], as depicted in Figure 4. This methodology allows accurate representation of the mass and inertia properties of the structural elements that compose the vehicle. It also includes the kinematic joints, which control the relative motion between the bodies, and the force elements, that represent suspension components of vehicle.

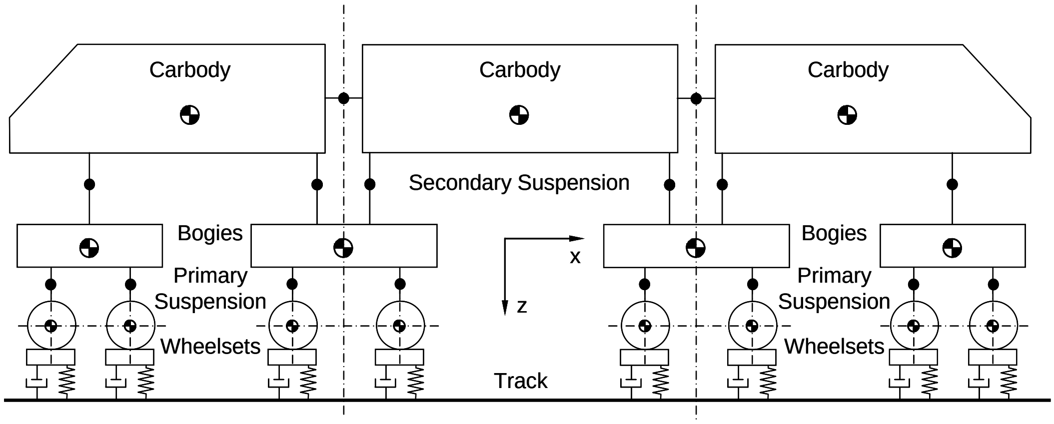


Figure 4: Multibody model of Vehicle 1

Vehicle 1 has two levels of suspension, the primary and the secondary. The primary suspension elements connect the bogie frame to the axleboxes of the wheelsets and are the main responsible for the steering capabilities and stability behaviour of the whole trainset. The carbody is supported by the bogies through secondary suspension elements. Their main function is to minimize the vibrations induced by the track on the passenger compartment, improving the comfort and reducing the problems associated with structural fatigue.

The multibody model of the railway vehicle represented in Figure 4 is composed by 15 rigid bodies. These are used to represent 3 carbodies, 4 bogie frames and 8 wheelsets. The rigid bodies are connected by elastic and viscous components, having linear and non-linear characteristics.

One of the main issues in railway dynamics is the compromise between running on straight tracks and negotiating curves. In a straight track it is advantageous to have a rigid primary suspension as it improves the vehicle stability. In a bogie with these characteristics, the yaw motions of the wheelsets relative to the bogie frame are very restricted. Such bogies have good ride stability properties and originate a rather high critical speed, but their performance in curves is poor [14,38].

In a curve, it is useful to have a flexible primary suspension in order to improve the curve negotiation performance of the trainset. This design principle allows a significant yaw motion of the wheelsets relative to the bogie frame and a good curving performance is achieved, as represented in Figure 5. However, instability may occur on tangent track if the longitudinal stiffness is too low [14,38].

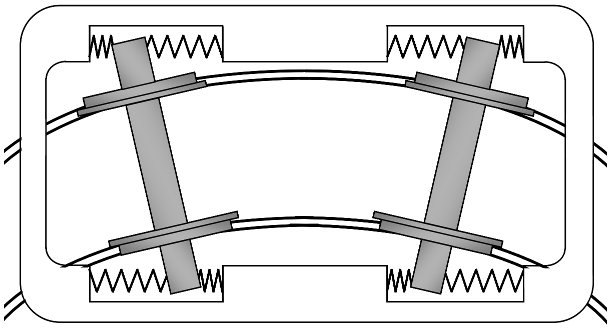


Figure 5: Yaw motion of wheelsets when negotiating a curve

The influence of the primary suspension stiffness on wheel wear progression is studied here by considering Vehicle 1 assembled with two different values for the longitudinal stiffness *Kx*. The primary suspension parameter *Kx*, represented in Figure 6, is changed in both motor and trailer bogies as follows:

- Reference value: *Kx* = K
- Modified value: *Kx* = K / 2

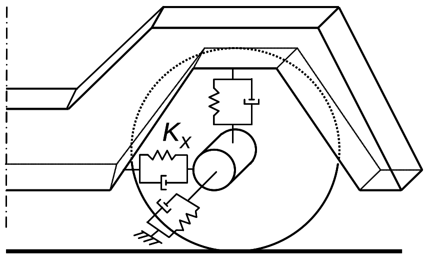


Figure 6: Representation of the primary suspension elements

The comparative wear study is made on the track between the cities of Cuneo and Ventimiglia, from the Italian railway network. This track has about 96 km length and it is particularly curved, with 61% of its curves having radii with less than 450 m, as represented in Figure 7. The vehicle is initially equipped with new wheels, with S1002 profile [1], and the track model is assembled with UIC60 rails [39] with 1/20 cant.

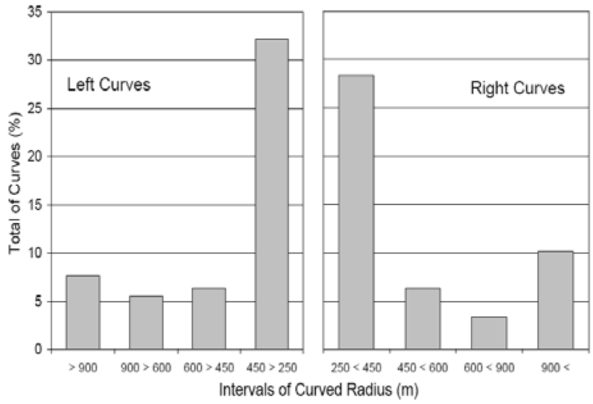


Figure 7: Curve radii distribution of the track

The wear computation is carried out by performing several outward and return journeys on the Cuneo-Ventimiglia track until reaching the total distance of 5000 km. The velocity of Vehicle 1 is varied between 80 and 95 km/h along the track length, which is in conformity with the service conditions on this track.

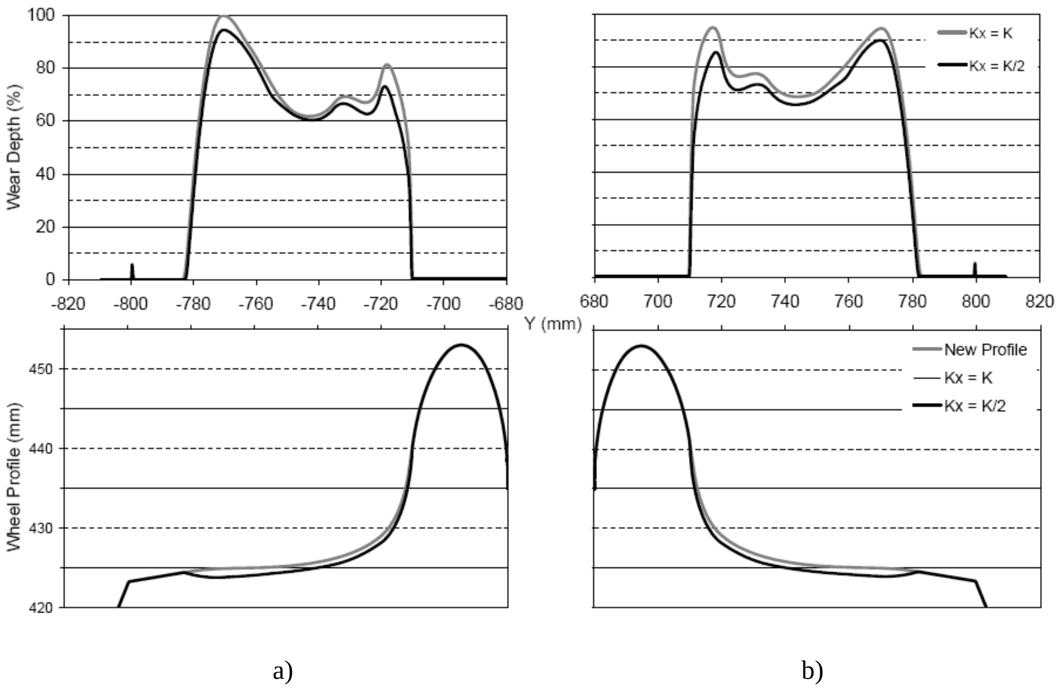


Figure 8: Wear results with different stiffness values of primary suspension on: a) Left wheel; b) Right wheel

In Figure 8, the wear results for the first wheelset of Vehicle 1, assembled with different stiffness values for the primary suspension, are presented. On the top of the figure, the comparison between the wear depth values is shown. These results are presented as a percentage of the maximum wear depth value obtained. The new and the worn profiles, on the left and right wheels, are given on the bottom of Figure 8. The results show that the levels of wear on both tread and flange zones are higher with the stiffer primary suspension. It is also observed that the wear distribution along the profiles is similar in the two cases.

In order to assess how the primary suspension stiffness affects the reprofiling intervals of the wheelsets of Vehicle 1, the worn profiles of all wheels are analysed. This evaluation is made by studying the evolution of the wheel wear parameters *Sh*, *Sd* and *qR* and by comparing them with the admissible values defined in Table 1. Such an approach can be used to predict when the profile parameters reach the limit values and, consequently, to estimate the corresponding reprofiling intervals. The results obtained with this methodology are summarized in Table 2. It is observed that the vehicle assembled with the softer primary suspension has an interval between reprofiling maintenance procedures that is 16.5% larger than the one of the vehicle equipped with the stiffer suspension.

Table 2: Summary of the influence of primary suspension stiffness on wear

Primary Suspension	Longitudinal Stiffness	Reprofiling Interval Variation
Reference Suspension	K	+ 16.5 %
Modified Suspension	K / 2	

4.2 Influence of rail cant

In modern railway networks, the rail profiles are shaped to fit together with the geometry of the wheels, especially when they are worn. In most cases, rails are mounted with an inclination inwards, as shown in Figure 9, because the wheel profiles are coned. Usually the rail cant varies between 1/40 and 1/20 but, in some turnouts, rails may be mounted without inclination. In the Italian railway network a 1/20 rail cant is usually used, whereas the German tracks are in general assembled with a rail cant of 1/40.

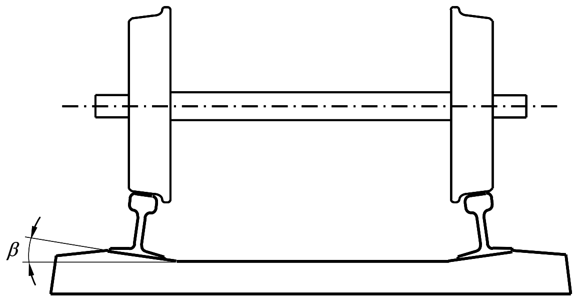
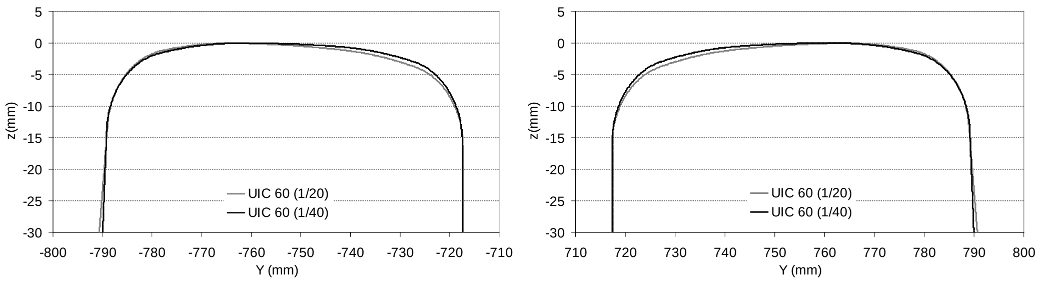


Figure 9: Rails mounted with an inclination inwards

The purpose of this case study is to evaluate the wheel wear sensitivity to the rail inclination. For this purpose, two wear computations are performed considering exactly the same service conditions, except the rail cant that has the following values:

- Reference rail cant 1/20: $\beta = 0.050$ rad = 2.86º;
- Alternative rail cant 1/40: $\beta = 0.025$ rad = 1.43º.



a) b)

Figure 10: UIC 60 rails mounted with an inclination of 1/20 and 1/40: a) Left; b) Right

In Figure 10 the UIC 60 rails mounted with an inclination inwards of 1/20 and 1/40 are represented. Despite the rail profiles being the same, the different cant influences the wheel-rail contact geometry and, consequently, the equivalent conicity [14,40,41], which is an important parameter used to evaluate the running stability of railway vehicles. The importance of the equivalent conicity results from the fact that the steering mechanism of a wheelset is not due to conicity, or change in rolling radius of one wheel, but due to the difference in rolling radii between left and right wheels.

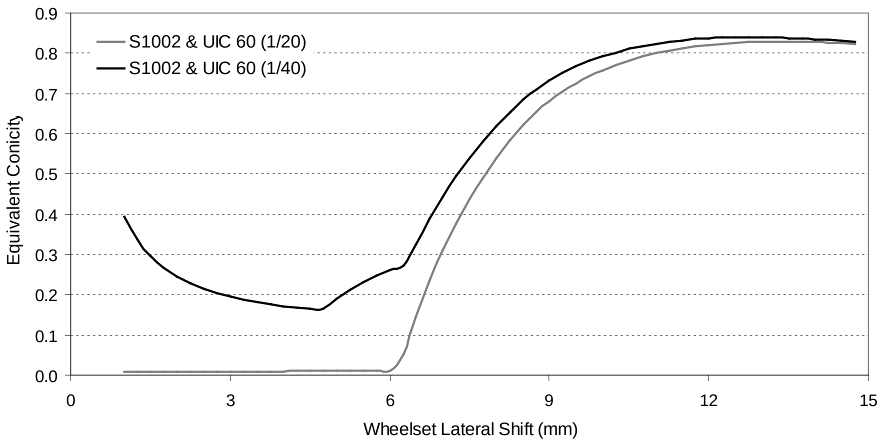


Figure 11: Equivalent conicity for wheel profile S1002 and rails UIC 60 with cant of 1/20 and 1/40

In general, the equivalent conicity is a nonlinear function of the wheelset lateral displacement and it depends on the geometric combination of both wheel and rail profiles. It also depends on the wheelset inside gauge, flange thickness, rail cant and track gauge. In Figure 11 the evolution of the equivalent conicity for a wheelset assembled with S1002 wheels and for UIC 60 rails with cant of 1/20 and of 1/40 is presented. It is observed that, for example, for 3 mm wheelset lateral shift with respect to the track centerline, the equivalent conicity for 1/20 rail cant is 0.01 whereas, for 1/40 rail cant, it has a value of 0.2. As the rail cant originates differences in the equivalent conicity, it will also affect the dynamic behaviour of the railway vehicles. This fact has repercussions on the wear evolution of the wheels.

The trainset considered here to study the consequences of the rail cant on the wheel wear growth is a non-articulated conventional trainset composed of seven vehicles interconnected by linking elements, as represented in Figure 12.

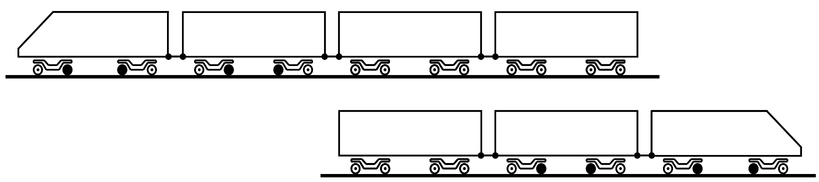


Figure 12: Non-articulated conventional trainset

Due to the trainset configuration, it is assumed that, concerning the wear studies performed here, the dynamic behaviour of each vehicle has a non-significant influence on the others. According to this assumption, each vehicle of the trainset can be studied independently, as shown in Figure 13. In this way, the vehicle model considered is composed only by one unit of the trainset, called hereafter as Vehicle 2. This composition is a motor vehicle that is assembled with two trailer wheelsets, represented in white, and two motor wheelsets, represented in black.

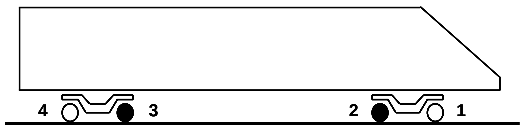


Figure 13: Vehicle 2 – Motor vehicle of non-articulated conventional trainset

The 3D model of Vehicle 2 is built using a multibody approach, as depicted in Figure 14. The vehicle model is composed by 1 carbody, 2 bogie frames, 2 carbody bolsters, 4 traction rods and 4 wheelsets. It also includes the kinematic joints, which control the relative motion between the bodies, and the force elements, that represent suspension components of vehicle.

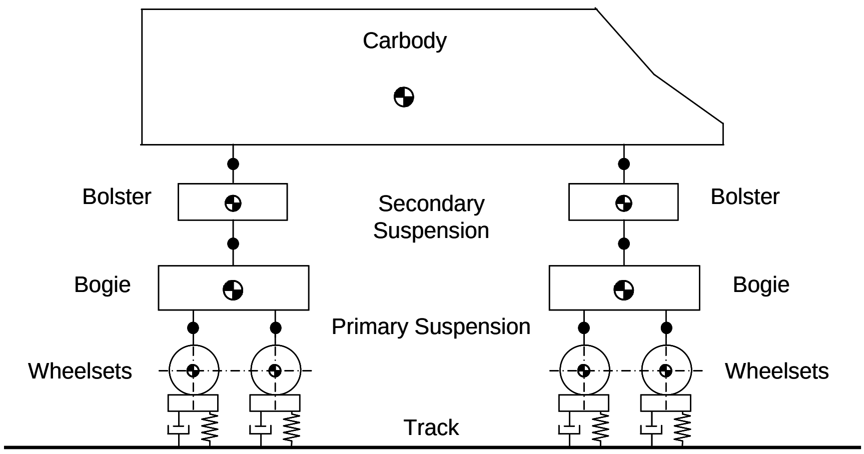


Figure 14: Multibody model of Vehicle 2

The primary suspension of Vehicle 2 is composed of two vertical coil springs, assembled laterally at each side of the axleboxes, and one vertical damper. It also includes an axle guide link system to transmit the longitudinal forces between the wheelsets and the bogie frame. The vertical displacements of the primary suspension elements are limited by a bumpstop and a liftstop, mounted at each axlebox.

The carbody is sprung against each bogie frame via a bolster and four flexi-coils. At both sides of the bogies, and assembled in parallel with each pair of coil springs, there is a vertical hydraulic damper. These elements are used for stabilization and also work as the vertical bumpstop and liftstop device of the secondary suspension. In order to guarantee a small roll coefficient, the bolsters are controlled in their roll movement by one anti-roll bar. The yaw movement of the bogies is limited through two anti yaw dampers assembled between the carbody and each side of the bogie frames.

In Vehicle 2, the connection between the carbody and each one of the bogies is realized by a pivot shaft. This element is rigidly fixed to the carbody and is assembled vertically, passing through the bolster and bogie frame without contacting them directly. A centre plate is rigidly fixed to the extremity of the pivot and it is hinged to the bogie frame by two longitudinal traction rods. This subsystem only ensures the vehicle steering functions, transmitting the in-plane loads between the carbody and bogie, but not the vertical loads, which are transmitted through the secondary suspension elements. The low attachment position between carbody and bogies minimizes the wheel load changes that develop during the vehicle traction and braking. The traction rods are assembled with rubber bushings at their extremities in order to ensure a better performance when the vehicle travels in small radius curved tracks. The lateral stabilization of the carbody is achieved through two pairs of transversal hydraulic dampers, assembled between the bogie frames and the carbody. The relative lateral displacement between the carbody and each bogie is limited by two transversal rubber bumpstops.

The track considered here is the one between the Italian cities of Cuneo and Ventimiglia that was described previously and which characteristics are shown in Figure 7. The comparative wear study is carried out by performing several outward and return journeys on the track until reaching the total distance of 5000 km. In agreement with the service conditions on this track, the velocity of Vehicle 2 is varied between 80 and 95 km/h.

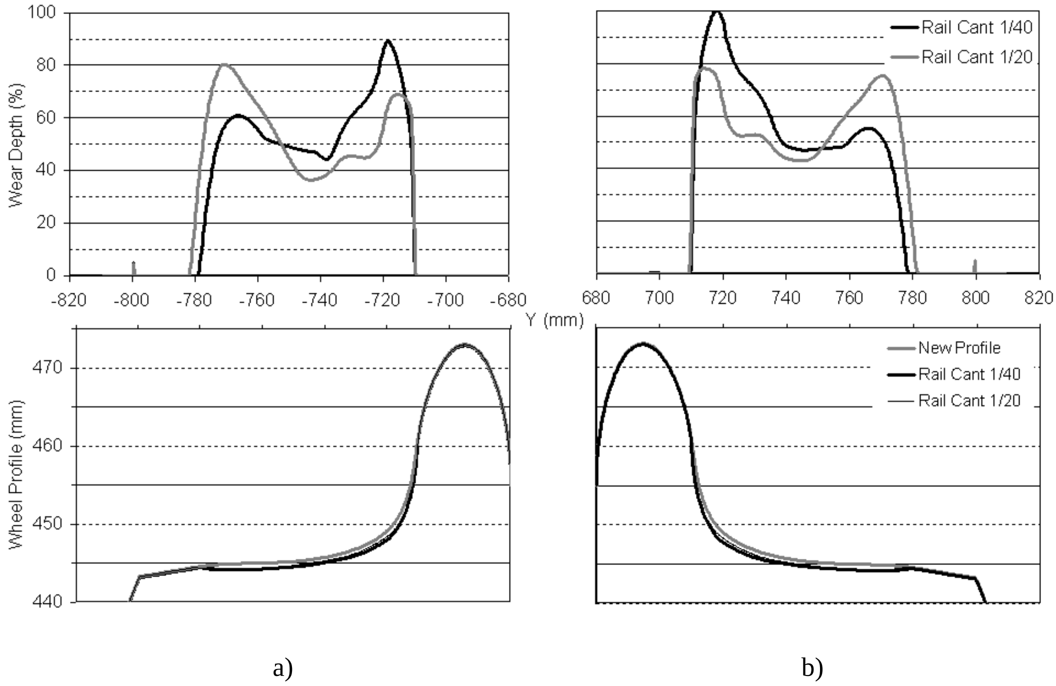


Figure 15: Wear results with rail cant of 1/20 and of 1/40 on: a) Left wheel; b) Right wheel

In Figure 15, the wear results for the first wheelset of Vehicle 2 are presented. On the top, the comparison between the wear depth values is shown, being the results presented as a percentage of the maximum wear depth value obtained. On the bottom of the figure, the new and the worn profiles are given. The results show that a rail cant of 1/20 produces more wear on the tread zone of the wheel profiles. On the other hand, a rail inclination of 1/40 originates more wear on the flange zone.

The results from Figure 15 can be explained by the fact that the wheels with a S1002 profile have the main part of the tread with a 1/40 cone. In such conditions, the rail with a 1/40 cant has its vertical axis perpendicular to the wheel tread, which implies that the contact area will be bigger than when using a rail with an inclination of 1/20. In order to study this issue in more detail, the variation of the contact patch on the left wheel of Vehicle 2 is shown in Figure 16. It is observed that for a positive lateral displacement of the wheelset with respect to the track, corresponding to a tread contact, the contact patch area is bigger with a 1/40 rail cant than with a 1/20. As the contact area is larger when using a 1/40 rail inclination, the stresses developed in the contact patch are smaller and, consequently, less wear will arise on the wheel tread.

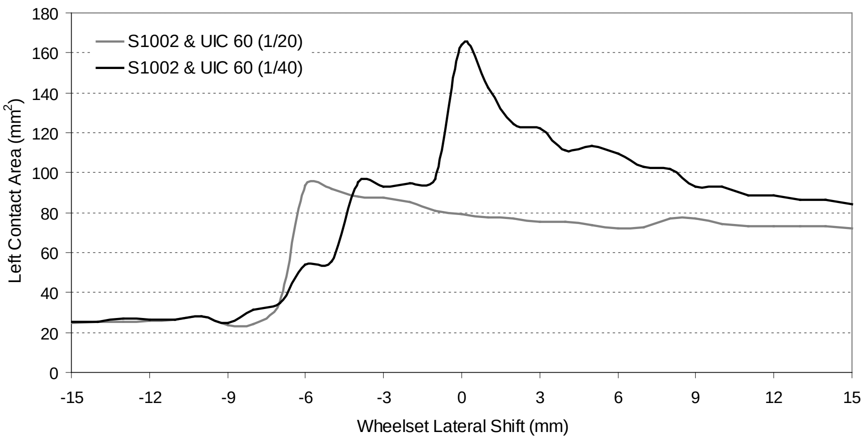


Figure 16: Contact area on the left wheel of Vehicle 2

The different rail cant also influences the wheel-rail contact geometry on the flange zone of the wheel profile. In fact, the results from Figure 16 show that, for a wheelset lateral shift lower than - 4 mm, the contact between wheel and rail occurs on the flange zone of the wheel profile. On that zone the contact area is smaller when using a UIC 60 rail with 1/40 cant. This implies that higher stresses and, consequently, more wear will appear on the wheel flange when using a rail inclination of 1/40.

With the purpose of assessing how the rail cant affects the reprofiling intervals of Vehicle 2, the worn profiles of all wheels are analysed. This evaluation is made as explained previously, i.e., by studying the evolution of the wheel wear parameters *Sh*, *Sd* and *qR* and by comparing them with the admissible values defined in Table 1. The results obtained in this way are summarized in Table 3, where the values of the equivalent conicity correspond to a wheelset lateral shift of 3 mm. It is observed that the use of a rail cant of 1/40 instead of 1/20 increases by 10.6% the reprofiling interval of the wheelsets of Vehicle 2.

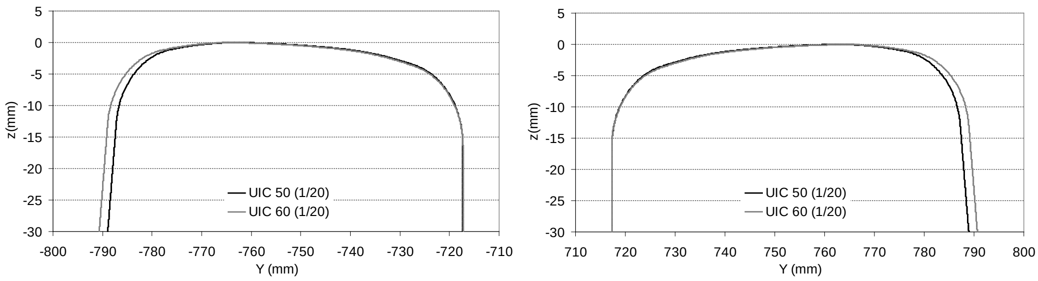
Table 3: Summary of the influence of rail cant on wear

Rail Cant	Equivalent Conicity	Reprofiling Interval Variation
Reference cant (1/20)	0.01	+ 10.6 %
Alternative cant (1/40)	0.20	

4.3 Influence of rail profile

The objective now is to investigate the wheel wear sensitivity to the rail profile used to assemble the track. For this purpose, two wear studies are performed considering the same operating conditions, except the rail profiles that are:

- Reference rail profile: UIC 60 (1/20);
- Alternative rail profile: UIC 50 (1/20).



a) b)

Figure 17: Comparison of UIC 60 and UIC 50 rail profiles

In Figure 17 a comparison between the UIC 60 and UIC 50 rail profiles is presented. It is observed that the geometry of both rails is nearly the same, with the UIC 60 rails being slightly wider. From this comparison it is evident that the wheel-rail contact geometry with both rail profiles will be similar. This statement can be verified in Figure 18 where the equivalent conicity is presented for a wheelset assembled with wheels having a S1002 profile and for rail profiles UIC 60 and UIC 50.

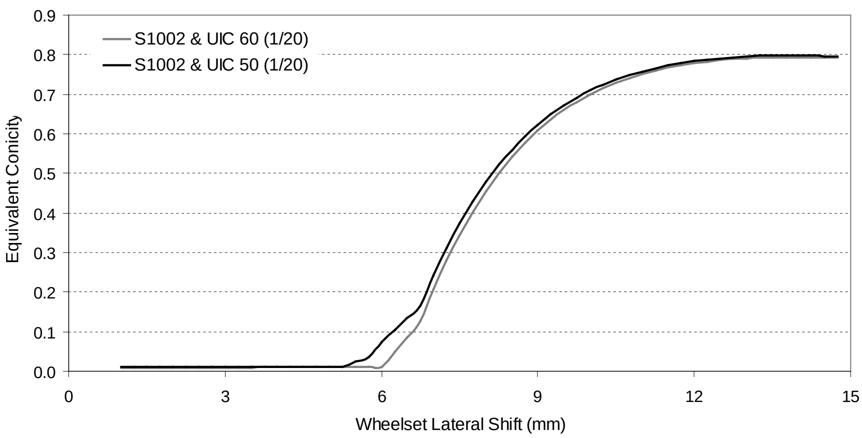


Figure 18: Equivalent conicity for wheel profile S1002 and rail profiles UIC 60 and UIC 50

As the two rail profiles considered here do not originate meaningful variations in the equivalent conicity, no relevant differences are expected in the dynamic behaviour of the railway vehicle since all other service conditions are equal. Consequently, it is expected that the wheel wear evolution will reveal no sensitivity to the variation of the rail profiles. In order to check these statements, two comparative wear studies are carried out by performing several outward and return journeys on the Cuneo-Ventimiglia track, which is characterized in Figure 7, until reaching the total distance of 5000 km. The vehicle model used is Vehicle 2, represented in Figure 14, and its velocity is varied between 80 and 95 km/h along the track length.

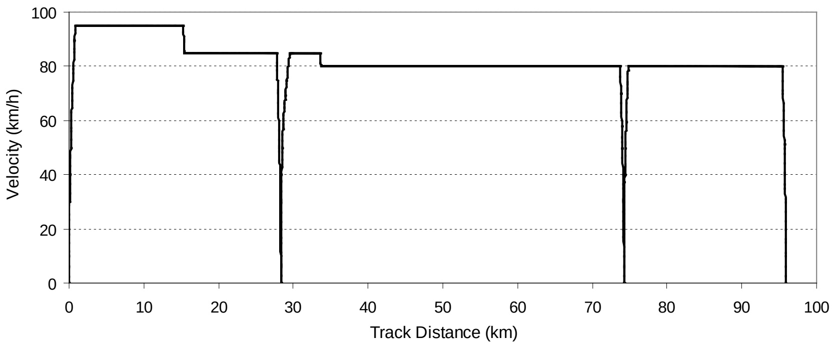
Following the same procedure described in the previous case studies, the analysis of the worn profiles of all wheels of Vehicle 2 allows the prediction of the reprofiling intervals of the wheelsets. The results obtained in this manner are summarized in Table 4. It is observed that the use of rail profile UIC 50 instead of UIC 60 originates a variation in the reprofiling interval that is less than 1%.

Table 4: Summary of the influence of rail profile on wear

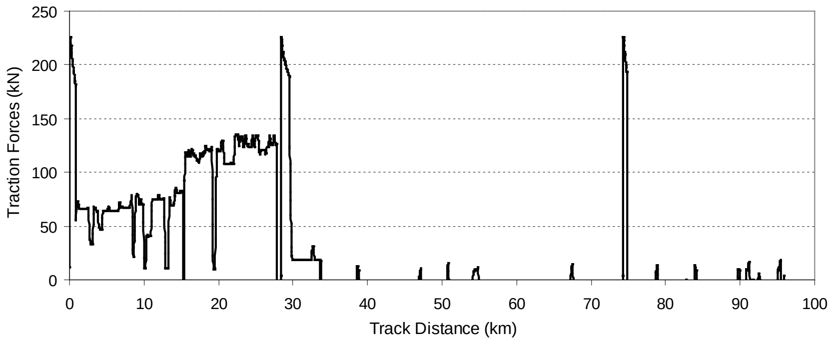
Rail Profile	Reprofiling Interval Variation
Reference profile: UIC 60 (1/20) Alternative profile: UIC 50 (1/20)	– 0.7 %

4.4 Influence of traction/braking forces

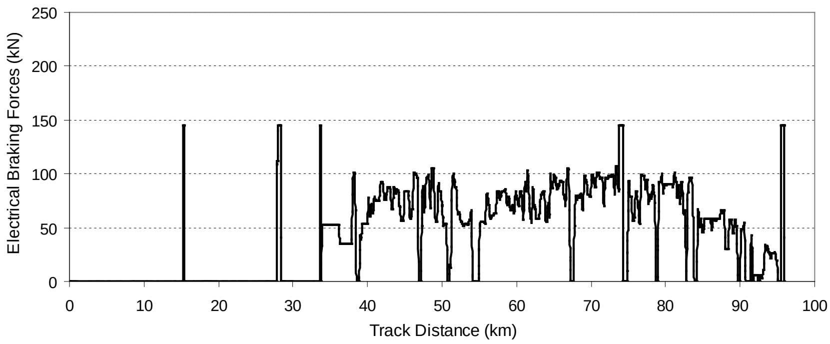
The aim of this case study is to evaluate the wheel wear sensitivity to the traction and braking forces that are applied on the wheelsets of the railway vehicles during their operation. For this purpose, two wear computations are performed. In one case, no traction/braking forces are considered whereas, in the other case, these loads are applied to the vehicle wheelsets during the dynamic analysis. All other service conditions and analysis parameters required for the wear studies remain unchanged.



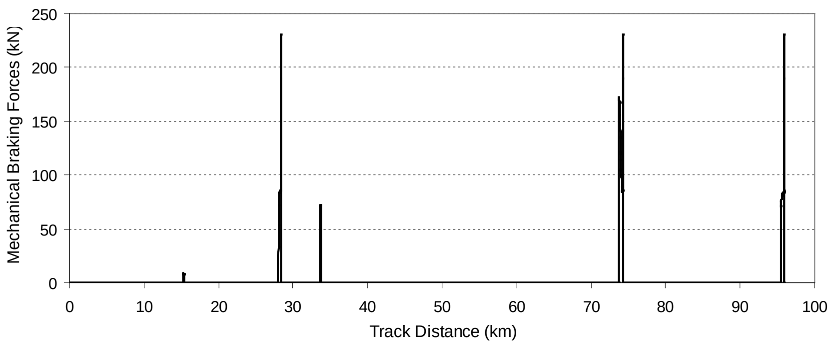
a)



b)



c)



d)

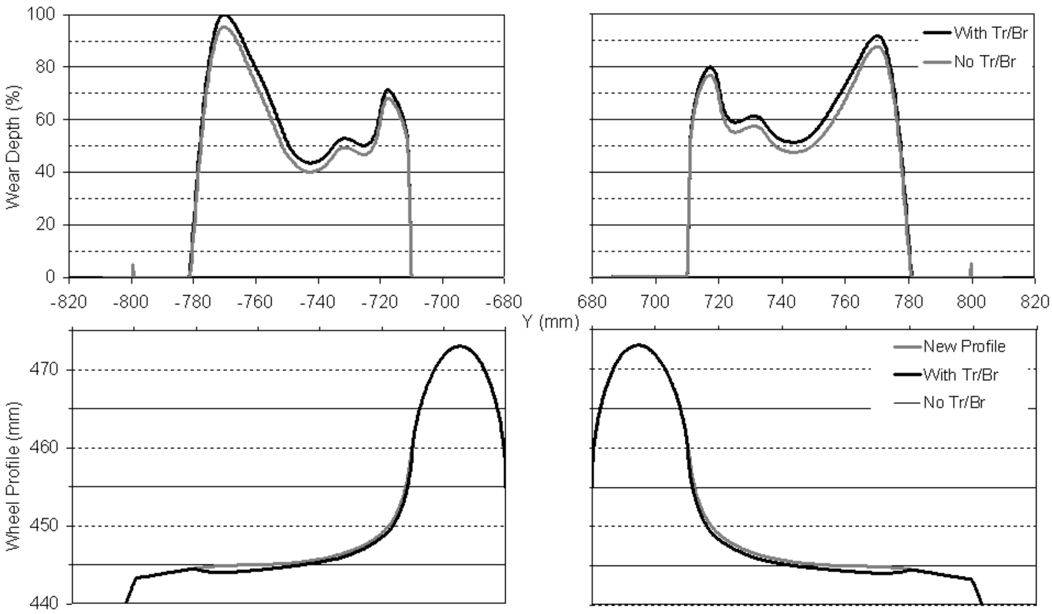
Figure 19: Characterization of the traction and braking forces: a) Velocity profile; b) Traction forces; c) Electrical braking forces; d) Mechanical braking forces

The wear evolution studies are executed by performing several outward and return journeys on the Cuneo-Ventimiglia track, which is characterized in Figure 7, until reaching the total distance of 5000 km. The vehicle model considered here is Vehicle 2. The velocity profile along the track length and the traction and braking forces that are applied during the wear computation are presented in Figure 19. This information is collected by the railway operator and it includes the braking and accelerations resultant from the train stops in the railway stations that exist in the Cuneo-Ventimiglia track.

The traction and braking forces are accounted for by applying the following torques on wheelsets of Vehicle 2, which is represented in Figure 13:

- Traction Forces: Applied on the motor wheelsets;
- Electrical Braking Forces: Applied on the motor wheelsets;
- Mechanical Braking Forces: Applied on motor and trailer wheelsets since both are equipped with brake discs.

In the comparative wear study performed here, only the motor wheelsets (2 and 3 in Figure 13) are studied due to the fact that they are applied with traction forces, electrical braking forces and mechanical braking forces, whereas the trailer wheelsets (1 and 4) are only subjected to the mechanical brakes. In addition, Figure 19d) reveals that this braking system is only used four times during trainset operation and for very short periods. Therefore, the traction/braking forces will have negligible consequences on the wear growth of the trailer wheelsets when compared with the repercussions on the motor ones. In Figure 20, the wear depth results and the new and worn wheel profiles are presented for the second wheelset of Vehicle 2. The results show that the levels of wear are slightly higher when considering the traction/braking forces.



a) b)

Figure 20: Wear results with and without traction/braking forces on: a) Left wheel; b) Right wheel

In order to characterize, in a more fundamental way, the influence of the traction/braking forces on the wheel wear growth, the geometry of the worn profiles is analysed through the wear parameters *Sh*, *Sd* and *qR*. The comparison of these geometric parameters with the limit values defined by the international standards allows estimating the reprofiling intervals of the wheelsets. The results obtained, using this approach, are summarized in Table 5.

Table 5: Summary of the influence of traction/braking forces on wear

Traction/Braking	Reprofiling Intervals according to Wear Parameters		
	Flange Height	Flange Thickness	Flange Slope Quota
No (Reference) Yes (Comparison)	– 10.6 %	+ 4.5 %	+ 2.5 %

With reference to Figure 2, the flange height (*Sh*) is the geometrical parameter used to evaluate the wear depth on the wheel tread. On this basis, the variation of the reprofiling intervals based on the analysis of *Sh* indicates that the traction/braking forces are prejudicial for the tread wear. In fact, when considering these forces, the reprofiling intervals due to problems related to tread wear decrease more than 10%. On the other hand, the analysis of the two geometrical parameters associated to the flange wear (*Sd* and *qR*) reveals that the traction/braking forces are slightly advantageous for the wear progression on this zone of the profiles. It is observed that these forces originate an increase of 4.5% in the reprofiling intervals due to problems related to the flange thickness and a marginal enhancement regarding the issues related to the flange slope quota. In any case, it should be noted that the negative influence of the traction/braking forces on the tread wear is much more relevant than the small benefits obtained for the flange wear.

4.5 Influence of vehicle velocity / cant deficiency

The objective of this case study is to analyse the wheel wear sensitivity to the service velocity and, consequently, the cant deficiency of the railway vehicles. When travelling in curves, the vehicles are subjected to centrifugal accelerations which originate forces that tend to displace them towards outside of the curve. In railway industry, this effect is counteracted by the track cant, i.e., by raising the outer rail with respect to the inner one. This solution reduces the perceived lateral acceleration when negotiating a curve and the respective forces.

The equilibrium cant, for a given curve radius and vehicle speed, corresponds to the value that originates zero track plane acceleration. In general, the track curves are designed to have an equilibrium cant for the nominal velocity conditions of the vehicles that operate on that line. Running in such conditions is advantageous for the passengers since they do not feel the centrifugal accelerations on curves. In addition, the vehicles produce a resultant vertical force through the centreline of the track. Thus, the vertical wheel-rail interaction forces are equal, so that maximum utilization of traction effort and minimum wear on wheels and rails can be realized [15].

A railway vehicle is running with cant deficiency when the track cant is not sufficient to assure zero track plane acceleration. In this case, a resultant force F_C pointing towards the outside of the curve arises, the passengers are pushed in that direction due to the centrifugal force and the vertical contact forces are higher on the outer wheels of the wheelsets, as depicted in Figure 21.

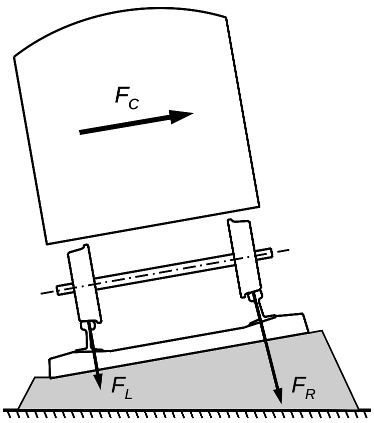


Figure 21: Vehicle running with cant deficiency

The study on the influence of the cant deficiency is performed here by running two wear computations considering the same operation conditions, except the vehicle speed, that has the following values:

- Reference velocity: Varied between 80 and 95 km/h along the track length, which is in conformity with the service conditions but originates cant deficiency in the majority of the curves;
- Reduced velocity: 45 km/h along the whole track length.

The two comparative wear studies are carried out by performing several outward and return journeys on the Cuneo-Ventimiglia track, which is characterized in Figure 7, until reaching the total distance of 5000 km. The vehicle model used is Vehicle 2, represented in Figure 14.

Following the methodology described in the previous case studies, the analysis of the worn profiles of all wheels of Vehicle 2 allows predicting its reprofiling intervals. The results, obtained using this approach, are summarized in Table 6. It is observed that the reduction to half of the vehicle velocity originates an increment of more than 20% in the reprofiling intervals of the vehicle wheelsets.

Table 6: Summary of the influence of vehicle velocity on wear

Vehicle Velocity	Reprofiling Interval Variation
Reference velocity: 80 to 95 km/h Reduced velocity: 45 km/h	+ 22.7 %

5 Conclusions

In this work a computational tool that is able to study the dynamic behaviour of railway vehicles in realistic operation scenarios and to predict the wheel wear evolution according to those service conditions is presented. The objective is to analyse how the wheel wear progression is sensitive to some physical parameters related to the vehicle characteristics and to the trainset service conditions. The assessment of the wear sensitivity to these parameters is made according to the international standards. Hence, the wheel wear representation is based on the profile parameters *Sd*, *Sh* and *qR*. The measurement of these geometrical parameters and its comparison with the limit values allows predicting the reprofiling intervals of the wheelsets.

The comparative study performed here to evaluate the wear sensitivity to the primary suspension stiffness reveals that the vehicle assembled with the softer primary suspension tends to produce less wheel wear on both tread and flange zones. This fact enables it to operate for larger distances before requiring the reprofiling of the wheelsets. These numerical results are in line with the expectations as the track considered here is particularly curved.

The study on how the wheel wear growth is influenced by the rail cant reveals that the reprofiling intervals obtained when running on the track with a rail cant of 1/40 are larger than when travelling on a track with a rail inclination of 1/20. This is a consequence of using a railway vehicle assembled with wheels having a S1002 profile. In fact, this wheel profile has a tread inclination of 1/40 that fits together with the UIC 60 (1/40) rail. In such conditions, the use of a rail cant of 1/40 is advantageous in terms of wheel wear progression. These results are in line with expectations and experience.

The influence of the rail profiles UIC 50 and UIC 60 on wear progression is also analysed here. This comparative study shows that the rail profiles have a negligible influence on the predicted reprofiling intervals. This is due to the fact that the profiles UIC 50 and UIC 60 have nearly the same geometry in the contact region, which implies that the wheel-rail contact geometry and the equivalent conicity are similar. As the other service conditions do not change, no significant differences are expected in the dynamic behaviour of the railway vehicle and, consequently, on the wheel wear evolution.

The characterization on how the traction/braking forces affect the wheel wear growth reveals that these forces originate more wear on the tread zone of the profiles and less wear on the wheel flange. Nevertheless, the wear computations also show that the negative influence of the traction/braking forces on the tread wear evolution is more relevant than the small benefits obtained for the flange wear.

The influence on wheel wear evolution of the vehicle velocity / cant deficiency is also studied in this work. The results obtained show that the reduction to half of the vehicle service speed originates an increment of more than 20% in the distance that the railway vehicle is able to run before requiring the reprofiling of its wheelsets. This is related to the fact that running at higher speeds originates cant deficiency. In such situation, unequal vertical wheel-rail interaction forces will arise, originating an overload of the outer wheels and, consequently, higher stresses and more wear.

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