# EFFECT OF TRACK GEOMETRY IRREGULARITIES ON WHEEL - RAIL IMPACT FORCES

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## SUMMARY

With a view to examining the wheel-rail impact forces due to track geometry irregularities, the simulations of wagon-track system dynamics have been carried out and are presented in this paper. Two types of Pacific National (PNL) wagons (120-ton coal and 79-ton container) containing new and worn wheels, and measured track geometry irregularities supplied by The Australian Rail Track Corporation (ARTC) have been used in the simulations. It is shown that the alignment irregularity contributes the most to the lateral impact whilst the vertical surface profile irregularity contributes the most to the vertical impact for these specific measured track irregularities. It is shown that the wagons with severely worn wheels could lead to wagon derailment. It is also shown that the increase of wagon speed generally increases the impact, and the lighter wagon is more sensitive to the increase of wagon speed.

## 1 INTRODUCTION

Currently, track maintenance plans and train speed setting are based on the measured track geometry irregularity data without any consideration to the dynamic responses at the interface of the wagon and track systems due to these track geometry irregularities, and the wheel and rail defects. As the safety, economy and passenger comfort are largely dictated by the system dynamics, it is prudent to develop decision support systems (DSS) for track maintenance planning and train speed setting based on the combined consideration of the track geometry irregularity inspection and the dynamic responses of the wagon and track systems. This paper reports some preliminary results of an ongoing research funded by the Rail CRC and carried out at the Centre for Railway Engineering (CRE). This project aims at using reasonable and reliable mathematical models to describe the interaction of wagon and track, and to predict the system dynamic behaviour due to wheel and track profile characteristics. There are numerous studies reported in the literature on the wheel-rail interaction ([1] ~ [4]) including the model of dynamics of wagon and track interaction developed by the first author ([3] ~ [4]).

This paper presents both the lateral and the vertical dynamic responses of wheel and rail interaction due to practical measured track geometry irregularities in The Australian Rail Track Corporation (ARTC) network. The effects of wagon condition (two types of wagon), wheel profile (new wheel profile and severely worn wheel profile) and wagon speed (60 km/h, 80 km/h and 100 km/h) are considered in the simulations reported in this paper.

## 2 TRACK GEOMETRY

The main purpose of track geometry inspection is to detect the track geometry irregularities that could endanger the safety and reliability of railway traffic and to assist the track engineers to plan track maintenance in the most efficient way. The track geometry measurements using a track recording car that runs at regular time intervals are essential to a successful track condition-based management process, which could allow condition forecasting and consequent maintenance planning.

Track geometry is mainly defined in terms of four irregularities, namely, cross level, vertical surface profile, gauge variation and alignment variation. Railway industry regards this track geometry irregularity data as suitable for track condition inspection and maintenance scheduling.

A section of concrete sleeper ballasted tangent track of standard gauge in ARTC network is considered for the simulation. Data measured at 0.5 m intervals provides the cross level, the left and right rail vertical surface profiles, the gauge variation, and the left and right rail alignment variations as shown in Fig. 1. The large irregularity variations are around the location between 700 m ~ 750 m.

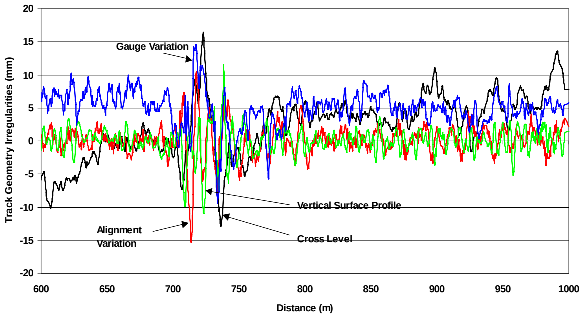



***Figure 1 – Measured Track Geometry Irregularities***

## 3 WAGON SYSTEMS

Two types of wagons are considered, namely, a 120-ton hopper coal wagon and a 79-ton container wagon. The 120-ton wagon contains self-steering bogies, secondary suspensions, and elastic pads between sideframes and axle boxes as the primary suspensions. The 79-ton wagon contains traditional three-piece bogies without primary suspensions.

## 4 SIMULATIONS

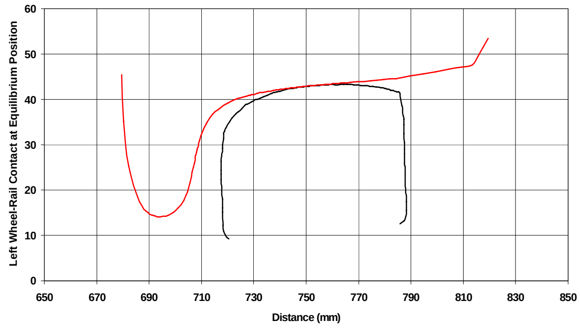
Two models, namely, the three-dimensional wagon and track system dynamics (3DWTSD) model developed by the first author, and the VAMPIRE package were used. In the absence of any measured data, it was required to examine the appropriateness of the results predicted. Hence, the choice of two independent programs was appropriate.

The simulations were carried out as follows:

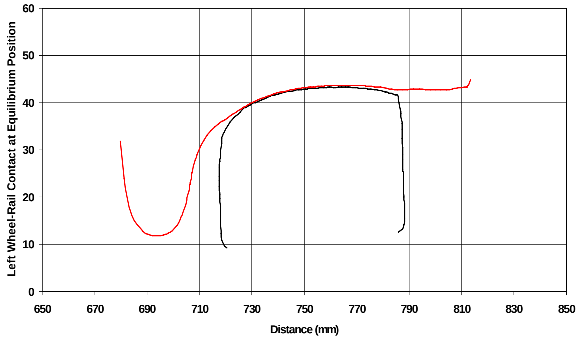
- Effect of each individual irregularity on wheel-rail impact forces—cross level, vertical surface profile, gauge variation and alignment variation.
- Effect of the combined irregularities on wheel-rail impact forces.
- Effect of wagon condition on wheel-rail impact forces – 120-ton coal wagon and 79-ton container wagon containing new and severely worn wheel profiles.
- Effect of wagon speeds on wheel-rail impact forces – 60 km/h, 80 km/h and 100 km/h.

A total of 36 analyses were carried out. The outputs are presented as wheel-rail lateral and vertical impact factors (wheel-rail contact force divided by static wheel load) and L/V ratios.

For all cases of the simulation runs, two types of wheel profiles, namely new and severely (severe tread hollowing) worn wheels were selected as shown in Fig. 2 (a) and (b) respectively, and wheel-rail contact parameters were determined and provided as "look-up" tables. Graphical representation of the contact parameters—in particular the radius of curvature and contact angle of wheel profile at the contact point are shown in Figs. 3 and 4 for the new and worn wheels respectively. In all simulations, the rail profile was kept in the as after-grinding condition, and wheels were considered to be perfectly circular.

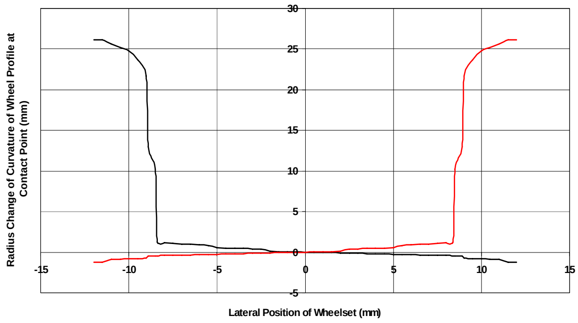



(a) New Wheel-Rail (After-Grinding) Profile

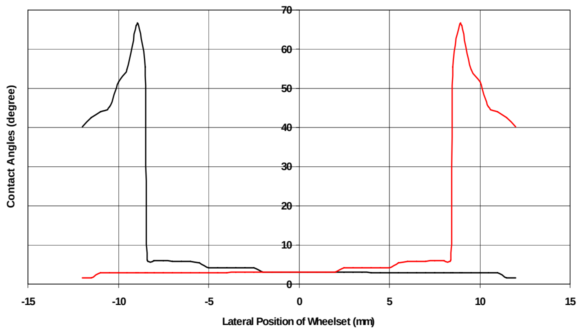



(b) Worn Wheel-Rail (After-Grinding) Profile

***Figure 2 – New Wheel and Worn Wheel-Rail (After-Grinding) Profiles***

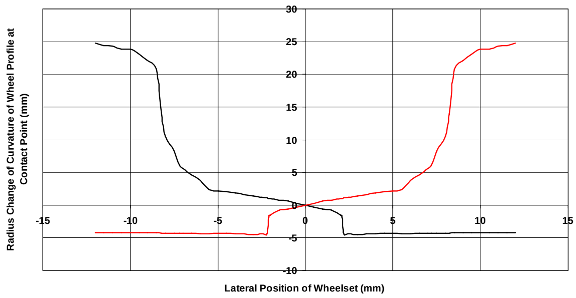



(a) Radius of Curvature of Wheel Profile at Contact Point

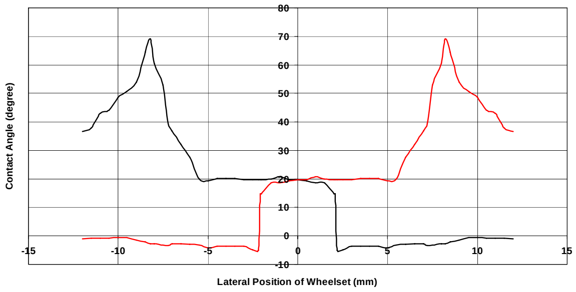



(b) Contact Angle

***Figure 3 – New Wheel Contact Parameters***




(a) Radius of Curvature of Wheel Profile at Contact Point




(b) Contact Angle

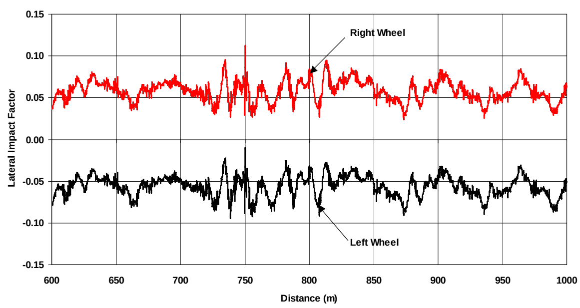
***Figure 4 – Worn Wheel Contact Parameters***

## 5 TRACK GEOMETRY EFFECTS ON WHEEL-RAIL IMPACT FORCES

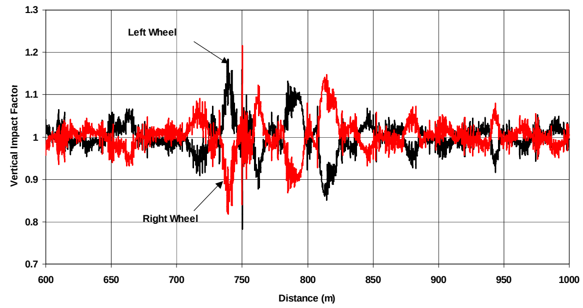
Figs. 5–9 show the wheel-rail lateral and vertical impact factors and L/V ratio due to various specific track geometry irregularities for the 120-ton wagon running with the new wheel profile at a speed of 80 km/h.

### 5.1 Cross Level

The lateral and vertical impact factors due to cross level irregularity are shown in Fig. 5 (a) and (b) respectively.




(a) Lateral Impact Factor



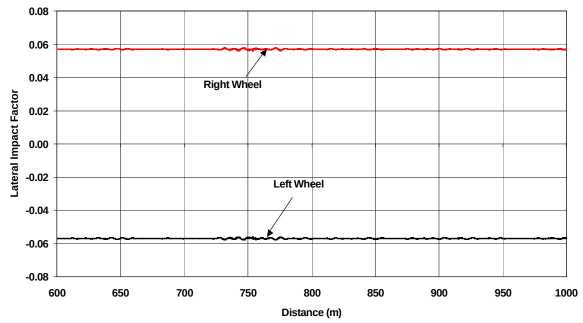

(b) Vertical Impact Factor

***Figure 5 – Impact Factors Due to Cross Level Irregularity***

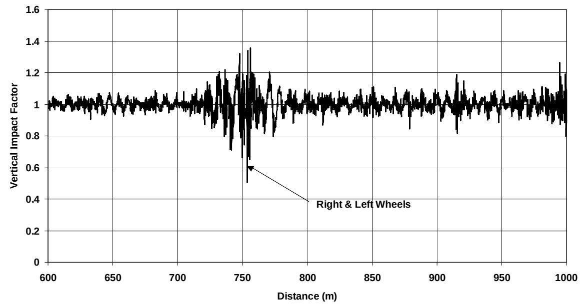
Although there is a large deviation of cross level from perfect track status as shown in Fig. 1, it can be seen from Fig. 5 (a) and (b) that the lateral impact factor changes only slightly around 0.05 whilst the vertical impact factor changes within the range of 0.8 to 1.2, and the impact factors on the right and left wheels vary in anti-phase due to cross level irregularity.

### 5.2 Vertical Surface Profile

Fig. 6 (a) and (b) show the lateral and vertical impact factors due to vertical surface profile irregularity.




(a) Lateral Impact Factor



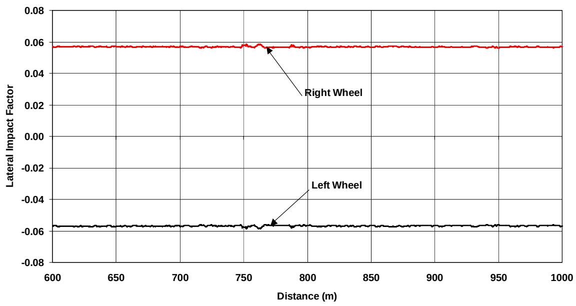

(b) Vertical Impact Factor

***Figure 6 – Impact Factors Due to Vertical Surface Profile Irregularity***

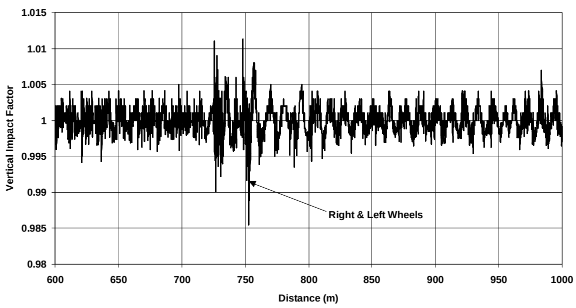
Because both rails are assumed to possess the same average vertical surface profile irregularity, the lateral impact factors for the right and left wheels shown in Fig. 6 (a) and the vertical impact factors for the right and left wheels shown in Fig. 6 (b) are exactly the same. Due to the large deviation of vertical surface profile as shown in Fig. 1, some large vertical impact factors are produced closer to the 750m section, with the maximum of about 1.36.

### 5.3 Gauge Variation

Fig. 7 (a) and (b) show the lateral and vertical impact factors due to gauge variation irregularity.




(a) Lateral Impact Factor



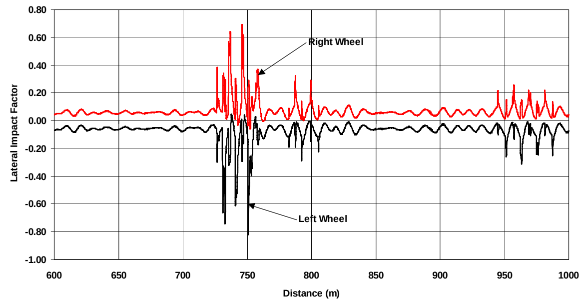

(b) Vertical Impact Factor

***Figure 7 – Impact Factors Due to Gauge Variation Irregularity***

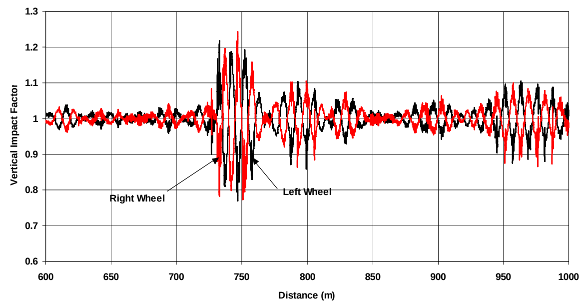
Although the minimum gauge variation below standard from Fig.1 is –9.4mm, the clearance between the wheel flange and the rail gauge face is about 8.5 mm, and the flange contact generates only very small lateral impact forces in this situation as shown in Fig. 7 (a). Also, the vertical impact factors as shown in Fig. 7 (b) do not change significantly.

### 5.4 Alignment Variation

The lateral and vertical impact factors due to the alignment variation irregularity are shown in Fig. 8 (a) and (b) respectively.




(a) Lateral Impact Factor



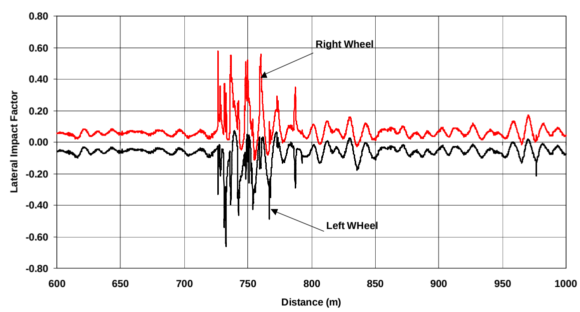

(b) Vertical Impact Factor

***Figure 8 – Impact Factors Due to Alignment Variation Irregularity***

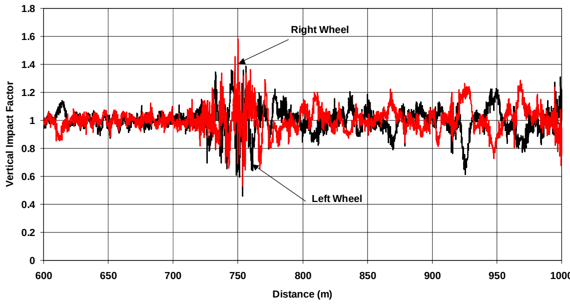
It can be seen from Fig. 8 (a) that the alignment variation causes large lateral impact forces. The large deviations in alignment have led to several heavy flange contacts, resulting in large lateral impact factors with the absolute maximum of 0.81. These flange contacts also produce large vertical impact factors as shown in Fig. 8 (b).

### 5.5 Combined Irregularities

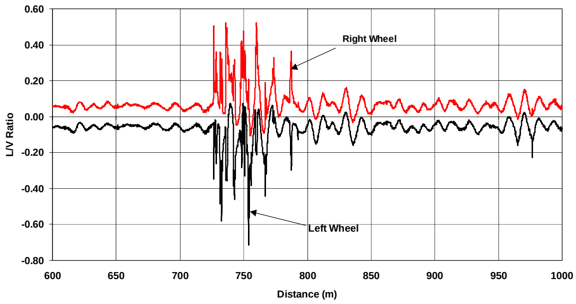
Fig. 9 (a), (b) and (c) show the lateral and vertical impact factors and the L/V ratio due to the combined irregularities for the 120-ton wagon running with the new wheel profile and at a speed of 80 km/h.




(a) Lateral Impact Factor




(b) Vertical Impact Factor



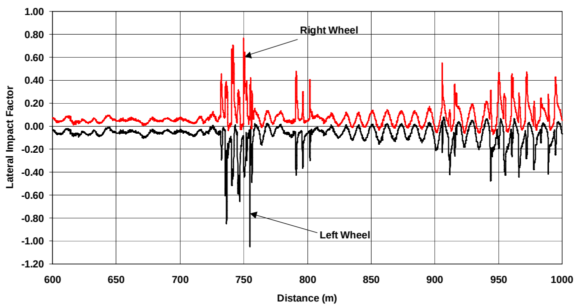

(c) L/V Ratio

***Figure 9 – Impact Factors and L/V Ratio Due to Combined Irregularities for 120-ton Wagon***

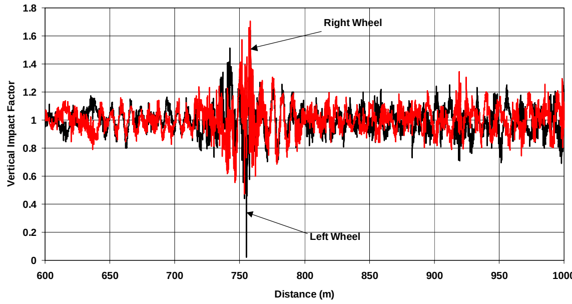
It can be seen from Fig. 9 (a) and (b) that for these specific track geometry irregularities the alignment variation mainly contributes to the lateral wheel-rail impact forces whilst the vertical surface profile mainly contributes to the vertical impact forces. The combined track geometry irregularities cause absolute maximum values of lateral and vertical impact factors and L/V ratio of 0.66, 1.58 and 0.72 respectively.

## 6 WAGON CONDITION EFFECTS ON WHEEL-RAIL IMPACT FORCES

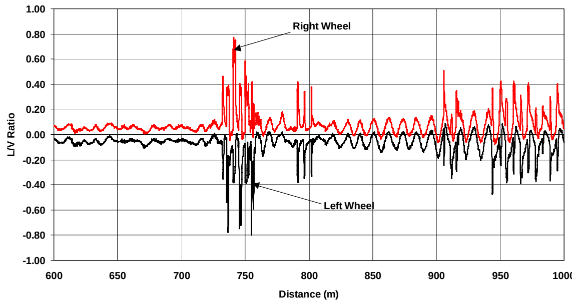
Fig. 10 (a), (b) and (c) show the lateral and vertical impact factors and the L/V ratio due to the combined irregularities for the 79-ton wagon running with the new wheel profile and at a speed of 80 km/h.




(a) Lateral Impact Factor




(b) Vertical Impact Factor

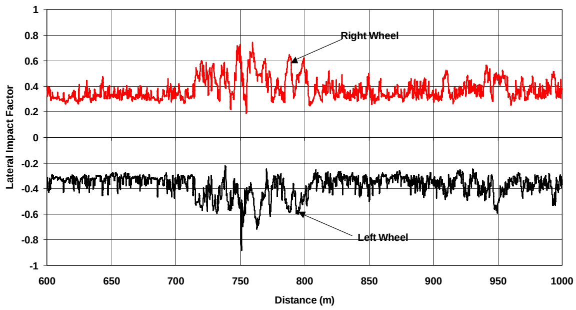



(c) L/V Ratio

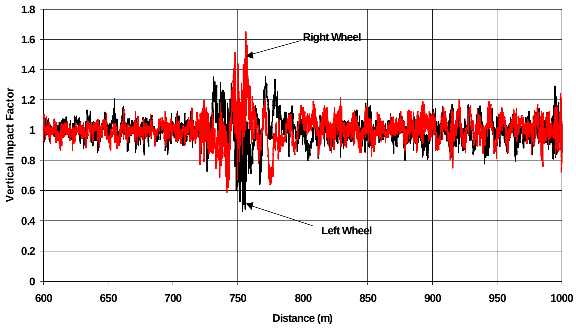
***Figure 10 – Impact Factors and L/V Ratio Due to Combined Irregularities for 79-ton Wagon***

It can be seen from Fig. 10 (a), (b) and (c) that the absolute maximum values of lateral and vertical impact factors and L/V ratio with 1.04, 1.70 and 0.80 produced by the 79-ton wagon are higher than those by the 120-ton wagon, with 57% increase for the lateral impact factor, 8% increase for the vertical impact factor and 12% increase for the L/V ratio. The higher values associated with the 79-ton wagon are also indicative of the higher lateral dynamics associated with 3-piece bogies relative to the primary sprung bogies in the 120-ton wagon, particularly at a speed of 80 km/h, which is within the hunting regime for the 3-piece bogies. The main reason for this may be due to the fact that the coal wagon design minimises the impacts between the wheel and the rail, as the primary suspensions in the 120-ton wagon can effectively reduce the unsprung mass that contributes to large impact forces.

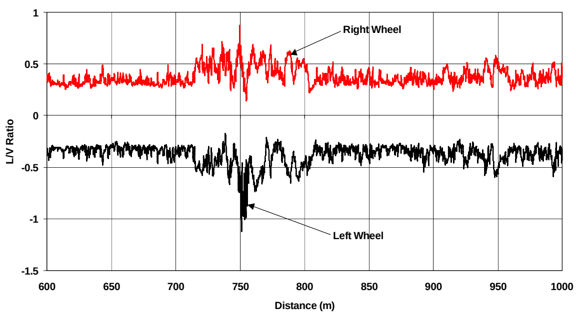
Fig. 11 (a), (b) and (c) show the lateral and vertical impact factors and the L/V ratio due to the combined irregularities for the 120-ton wagon running with the worn wheel profile and at a speed of 80 km/h.




(a) Lateral Impact Factor




(b) Vertical Impact Factor




(c) L/V Ratio

***Figure 11 – Impact Factors and L/V Ratio Due to Combined Irregularities for 120-ton Wagon with Severely Worn Wheels***

It can be seen from Fig. 11 (a) that the severely worn wheel increases the lateral impact factors significantly whilst the vertical impact factors are affected much less as shown in Fig. 11 (b). In this situation, the absolute maximum values of lateral and vertical impact factors and L/V ratio increase by 27%, 3% and 61% compared with the wagon running with the new wheel profile. It can be also seen that the L/V ratio on the left wheel shown in Fig. 11 (c) is over 1.0, which would increase the wagon derailment potential.

## 7 WAGON SPEED EFFECTS ON WHEEL-RAIL IMPACT FORCES

It is well known that the wagon operation speed significantly influences the dynamic interaction of the wagon and track systems. In order to examine the effects of wagon speed on the wheel-rail impact forces, simulations were carried out for both 120-ton and 79-ton wagons running with the new wheel profile and at the speeds of 60 km/h, 80 km/h and 100 km/h. Table 1 lists the lateral and vertical impact factors and the L/V ratios for these three speeds.

| Wagon | Speed (km/h) | Lateral Impact Factor | Vertical Impact Factor | L/V Ratio |
|---|---|---|---|---|
| 120 ton | 60 | 0.57 | 1.36 | 0.67 |
| | 80 | 0.66 | 1.58 | 0.72 |
| | 100 | 0.67 | 1.74 | 0.73 |
| 79 ton | 60 | 0.73 | 1.53 | 0.68 |
| | 80 | 1.04 | 1.70 | 0.80 |
| | 100 | 1.09 | 2.24 | 0.83 |

***Table 1 – Lateral and Vertical Impact Factors and L/V ratios for New Wheel-Rail (after-Grinding) Profile***

From Table 1, when the speed increases from 60 km/h to 100 km/h, the lateral and vertical impact factors and L/V ratios increase by 17%, 28% and 9% for the 120-ton wagon and by 49%, 47% and 23% for the 79-ton wagon. It can be seen that the lighter wagon is more sensitive to the speed increase.

## 8 CONCLUSIONS

From the simulations it could be concluded that the track geometry irregularities cause significant dynamic interaction between the wagon and track systems. In the specific cases dealt with in this paper, the alignment variation mainly contributes to the lateral dynamic interaction, leading to large lateral impact factors with the absolute maximum of 0.81 whilst the vertical surface profile contributes most to the vertical dynamic interaction, resulting in large vertical impact factors with the absolute maximum of about 1.36.

Wagon condition also significantly affects the dynamic interaction. The primary suspensions of the heavier wagon effectively restrain and reduce the dynamic impact. The absolute maximum values of lateral and vertical impact factors and L/V ratio produced by the 79-ton wagon increase by 57%, 8%, and 12% respectively, comparing with those by the 120-ton wagon.

The wagons with severely worn wheels increase the lateral dynamic impact significantly. The absolute maximum values of lateral impact factor and L/V ratio generated by the wagons with severely worn wheels increase by 27% and 61%

compared with the wagons running with the new wheel profile.

The higher the wagon operation speed, the larger the dynamic impacts both laterally and vertically. For example, when the speed increases from 60 km/h to 100 km/h, the lateral and vertical impact factors and L/V ratios increase by 17%, 28% and 9% for the 120-ton wagon. However, the lighter wagon would be more sensitive to the increase in speed, for example, the corresponding values are 49%, 47% and 23% for the 79-ton wagon.

The work has also clearly shown that the procedures can provide a very useful tool for determining the track geometry and wheel/rail condition standards that need to be adopted to reduce the dynamic lateral and vertical forces to acceptable levels, for different types of wagons operating at different speeds.

## 9 ACKNOWLEDGEMENTS

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