SOME RESULTS OF PERFORMANCE INDICATORS OF A RAILWAY TRACK OBTAINED DURING ITS RENEWAL PROCESS

Fortunato E.
Research Officer – Laboratório Nacional de Engenharia Civil, Portugal – efortunato@lnec.pt
Pinelo A.
Vice President – Estradas de Portugal, E.P.E, Portugal – apinelo@estradasdeportugal.pt
Lobo da Costa J.
General Manager – Somague Itinere – jllcosta@somague.pt
Gonçalves D.
Project Director – Rede Ferroviária Nacional, E.P., Portugal – dbgoncalves@refer.pt
Pratas A.
Technical Coordinator – Rede Ferroviária Nacional, E.P., Portugal – ampratas@refer.pt

ABSTRACT

In the scope of the modernization of the old railways, particularly when it is necessary to make the renewal of the platform, it is important to have performance indicators of the railway track that permit to evaluate its quality, to design the set of works to be done and to compare the behaviour of old platform with the one obtained after the renewal.

In modern railway track the stability of the geometry of the rails along the time and the space is one of the major performance indicators. The loss of the geometric regularity depends on the behaviour of the superstructure and substructure and usually occurs as a result of the degradation of the railway track, due to the repeated passage of the trains and of the seasonal variation in the weather conditions.

The analysis of the evolution of the geometric parameters of the railway track allows to identify both the poor performance sections and the variation of the conditions of one delimited section along the time.

This paper presents and analyses some results of the performance indicators of the track, obtained from geometric parameters, before and after the renewal of the two tracks of the most important Portuguese railway line (Northern Line).

To determine the geometric parameters, a Track Inspection Vehicle was used. That analysis was performed along 30 km, before and after the renewal works.

The significant improvement in the values of the performance indicators of the track, as a result of the renewal of the railway platform, is one aspect that guarantees the appropriateness of the works that have been carried out.

Keywords: railway platform, Track Quality Index, renewal

1. INTRODUCTION

Many railway lines integrated in the railway networks of several countries have been in operation for more than a hundred years in spite of their construction was made with reduced technological means and their design was based on empirical criteria, specially as regards geotechnical aspects. Aiming at adapting railway lines to new performance requirements, various administrations, namely in Europe, have invested in the modernization of railway infrastructures by taking advantage of using the existing corridors and substructures.

The collection of historical data related with track construction, maintenance, rehabilitation and performance, associated with a thorough visual inspection, are expected to make it possible to carry out an overall evaluation of its quality and to allow for the organisation of elements that permit to identify zones with distinct behaviour. In the last few years, some types of computer software have been developed aiming at supporting the maintenance management. Such software incorporates databases and behaviour models, which make it possible to manage the maintenance and rehabilitation of the railway track and to predict renewal actions (Rivier, 1998; Jovanovic & Zaalberg, 2000).

Within the framework of the modernisation of old railway lines, particularly in the case of renewal of the railway platform, it is important to have track performance indicators, which provide the possibility to assess its performance, to design the interventions and to compare the performances before and after intervention.

In modern railway tracks, the maintenance of the geometric regularity of rails, both in space and time, is one of the main performance indicators. The loss of that regularity depends on the behaviour of both the superstructure and the substructure and usually occurs as a result of the deterioration of the track, due to the repeated passage of trains, together with the variation in the weather conditions. The systematic monitoring of the conditions of the track geometry and the establishment of performance indicators, based on geometric parameters, may be very useful to analyse the performance.

The Track Inspection Vehicle (TIV) is a widely used equipment to analyse the geometry of the railway track. The use of a monitoring vehicle circulating at a speed similar to the one of a regular train, makes it possible to assess the track performance, in a more realistic way than with other methods, since the records are obtained under dynamic loading conditions similar to those occurred during the passage of trains. That equipment allows the continuous representation of the longitudinal and cross sections using non-destructive technologies and therefore does not require the interruption of traffic.

The analysis of records is made easier by the available computer hardware and software. In this way it is possible to collect and process a large amount of data, thus producing good quality and easy to interpret information.

The comparison, at each instant, of the values of variables under analysis with previously established reference values, makes it possible to assess the performance of the serviceable track, to obtain information related with the quality of the maintenance and rehabilitation works, and also, to make decisions associated with the scheduling of the future works.

Within the framework of the renewal of the railway platform of the most important Portuguese railway line (Northern Line), the analysis of the geometric parameters of the railway track, obtained in different periods, has contributed to establish the type of geotechnical characterisation required before the design stage and the type of designed interventions (Fortunato, 2005).

The comparison of the values of the indicators obtained on the basis of the geometric parameters, before the intervention, with those obtained after the renewal works, in a 30 km section, has made it possible to conclude that the works performed have led to a significant increase in the quality of the substructure, namely of the platform.

2. DETERMINING THE GEOMETRIC PARAMETERS AND THE PERFORMANCE INDICATORS OF A RAILWAY TRACK

The basic parameters characterising the track geometry are the two degrees of freedom of each rail. These four degrees of freedom are normally replaced by an equivalent system. To determine the basic track geometry, the parameters to be measured are the following: longitudinal level of both rails, horizontal curvature of both rails, track gauge, cross-level (superelevation), track twist.

The different parameters, both numerically and graph recorded, provide a real time information, which allow to assess when the values measured are within the intervals required, as regards for instance: acceptance requirements of new or renewed lines; track maintenance requirements and safety requirements.

The data used in this work for the geometric characterisation of the track were obtained by a Track Inspection Vehicle (TIV) Plasser & Theurer EM 120 (Figure 1).

Figure 1 Aspect of the Track Inspection Vehicle

The geometric parameters are calculated using the data regarding the successive positions of rails in the 3D space. Furthermore, neither direct measurements are performed on fixed points nor any physical contact with the track occurs during the measurement process. As regards the analysis of the parameters defined by geometric chords (alignment and levelling), the system has a high versatility because it makes it possible to choose the intended chords and the analysis of these parameters through the filtering of wavelengths.

When the vehicle starts moving, the system performs measurements with a 200 Hz frequency, i.e., at every 0.005 seconds, a new rail position is defined. The new position is obtained by two procedures – gyroscope system and accelerometer system – of which the results are compared and corrected, if necessary, by the information provided by the GPS, which performs readings at 1 Hz frequency.

The TIV is equipped with computer applications to automatically determine: i) all stretches of track in which one or more geometric parameters exceed the corresponding tolerance, their length, the maximum value and the corresponding location; ii) the track performance indicators in real time, based on variations in the acceleration, considering the maximum allowable speed on the track.

The geometric parameters acceptable tolerance depends on the speed on the track and on the classification of the latter. Table 1 contains the values considered in the case of acceptance of both new and renewed lines, in Portugal.

The tolerance establishing the maximum deviations can be associated with either the frequency or with the amplitude of the deviations.

Table 1 Tolerances of the geometric parameters according to line classification

Track Classes		Class–I	Class–II	Class–IIII	Class–IV
Parameters / Speed (V) (km/h)		V≥160	160>V≥120	120>V≥80	80>V
Cross level (mm)		2	2	3	4
Twist – base of 3 m (mm/m)		0.8	1	1	1.5
Level (mm)	Base ≤ 15 m	2	3	4	5
	15 m<Base≤25 m	3	4	5	6
Alignment (mm)	10 m chord	2	3	4	5
Gauge (mm)	Increase	2	2	3	3
	Decrease	-1	-1	-2	-2

To analyse the data, performance indicators are usually used, which make it possible to establish qualitative classifications based on geometric parameters. The following indicators were used: i) Levelling Quality Index (TAMP); ii) Alignment Quality Index (LINE); iii) Gauge Quality Index (GAGE); iv) Track Quality Index (TQI).

The indicators above presented are obtained based on various geometric parameters and by weighing up the characteristics and type of the track, using the relationships:

$$TAMP = K_1.A.V^B \frac{1}{N}\sum_{j=1}^{N}\sqrt{\Delta v_j^2 + \Delta u_j^2} \quad \text{(Eq. 1)}$$

$$LINE = K_2.A.V^B \frac{1}{N}\sum_{j=1}^{N}\left|\Delta h_j\right| \quad \text{(Eq. 2)}$$

$$TQI = K_3.A.V^B \frac{1}{N}\sum_{j=1}^{N}\sqrt{\Delta v_j^2 + \left(\left|\Delta h_j\right| + \left|\Delta u_j\right|\right)^2} \quad \text{(Eq. 3)}$$

$$GAGE = K_4.A.V^B \frac{1}{N}\sum_{j=1}^{N}\left|\Delta d_j\right| \quad \text{(Eq. 4)}$$

being:

- Δv – vertical variation of the position of the centre of gravity of the vehicle (mm);
- $\Delta h + \Delta u$ – horizontal variation of the position of the centre of gravity of the vehicle (mm);
- Δd – variation of the gauge comparatively with the standard gauge, which in Portugal is 1668 mm (mm);
- A, B, K_i – constants;
- N – number of comparisons;
- V – speed of the vehicle (km/h).

The parameters needed to calculate those indicators are obtained through (Figure 2):

$$\Delta v = \frac{\Delta v_E + \Delta v_D}{2} \quad \text{(Eq. 5)}$$

$$\Delta u = \Delta v_E - \Delta v_D \quad \text{(Eq. 6)}$$

$$\Delta h = \frac{\Delta h_E + \Delta h_D}{2} \quad \text{(Eq. 7)}$$

being:

- Δv_E, Δv_D – variation in the deflection measured in the vertical direction between cross-sections *i* and *i+1*, referring to the left and right rails, respectively;
- Δh_E, Δh_D – variation in the deflection measured in the horizontal direction between cross-sections *i* and *i+1*, referring to the left and right rails, respectively.

The quality index normally used is the TQI, because it is assumed to be an overall index, within the railway engineering.

The criterion used to define the track quality level is the one presented in Table 2.

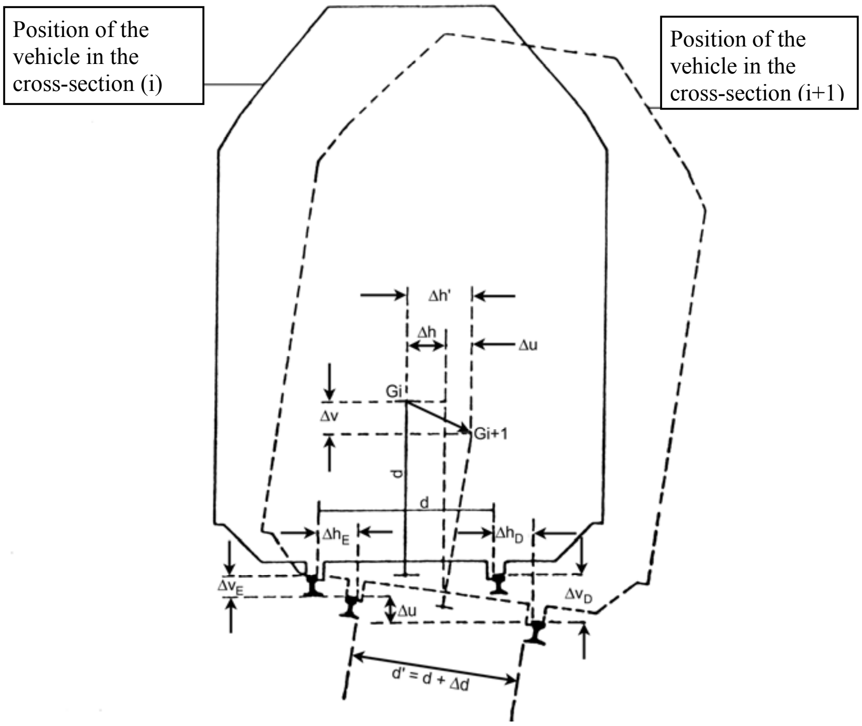


Figure 2 Variation of the centre of gravity due to geometric defects

Table 2 Track quality level

TQI	Quality level
0 ≤ TQI ≤ 150	Good
150 < TQI ≤ 200	Acceptable
200 < TQI ≤ 250	Defective
250 < TQI	Poor

The use of TIV makes it possible to carry out two types of studies. On one hand, a micro-analysis is performed through the analysis of the graph of the geometric parameters, of the listing of defects, of the brief report on defects and of the variation in the performance indicators, in sections with a previously established length. This analysis is leading to occasional interventions with the purpose of eliminating defects.

On the other hand, a macro-analysis is possible through the study and the statistical analysis of the performance indicators, makes possible to establish comparisons between the values obtained in different periods, to develop co-relations between the deterioration rate of the track and the operation conditions (speed, volume and type of traffic) and between that deterioration and the characteristics of the elements integrating it, either part of the superstructure or of the substructure. This analysis contributes to the definition of the general track maintenance policy, as well as to the definition of action strategies and of the allocation of resources.

The analysis of the nominal values presented in Table 1 makes it possible to conclude that the values assumed for the tolerances of the various geometric parameters have a magnitude that is unusual in Civil Engineering structures. Therefore, for a good track performance, it is essential to guarantee the adequate behaviour of its several elements, particularly substructure ones.

The track analysis method, which has been briefly presented, is the most relevant from a railway viewpoint. Nevertheless, the analysis of the characteristics of the substructure of the track using that methodology has the disadvantage to integrate some phenomena that are unrelated with its performance as, for instance, the particularities of the track and(or) the defects of the superstructure. Furthermore, as regards the substructure, the quality of the support of sleepers, which depends on the local arrangement of the ballast layer placed under the sleeper, influences decisively the results obtained and does not allow for a proper characterisation of the underlying layers.

3. ANALYSIS OF RESULTS OBTAINED WITH THE TRACK INSPECTION VEHICLE BEFORE AND AFTER RENEWAL

The Northern Line in Portugal is a railway line linking the two largest Portuguese cities – Lisbon and Oporto –, in a double track along about 340 km. The Downward Track (*DT*) (Oporto-Lisbon) of the Northern Line was constructed between 1856 and 1864 and the Upward Track (*UT*) (Lisbon-Oporto) between 1861 and 1930.

The main objectives of the renewal works performed (Fortunato et al., 2001) were to permit the circulation of passenger trains with a maximum axle load of 140 kN/axle, at a maximum speed of 220 km/h and the use of the same line by freight trains with a maximum axle load of 225 kN/axle, at a maximum speed of 100 km/h.

Before the beginning of works, the tracks usually consisted of twin-block sleepers, with a total length of 2.47 m, placed with a longitudinal spacing between axles of 0.60 m, on a ballast layer of variable thickness, settled on the earthwork platform.

The renewal designs defined a superstructure with 60 kgf/m rails on Iberian gauge (1.668 m), with prestressed concrete monoblock sleepers (2.60 m length and 304 kgf weight) placed every 0.60 m and on a 0.30 m thick granite ballast layer.

A sub-ballast layer was designed taking into account the new design requirements, the analysis of the old platform performance, the results of tests performed to characterise the platform and the conditions defined in UIC CODE 719R (UIC, 1994). At the top of the sub-ballast layer, it has been established that the value of the equivalent modulus of deformability obtained in the second cycle of the plate load test, EV2 (LCPC, 1973), would be equal or higher than 120 MPa.

The sub-ballast layer was settled on a good quality platform, characterised by an EV2 value higher than 80 MPa. When the measured EV2 value was less than 80 MPa it was built a granular crushed material capping layer with good mechanical characteristics, before the construction of the sub-ballast. At the sections considered as unstable, where the old platform was in a highly weathered condition and, therefore, presented a poor performance, it was necessary to remove the existing soils and to place a substitution layer and a capping layer under the sub-ballast.

The geometric parameters and the performance indicators have been determined on the renewed and already in service sections.

Figures 3 to 6 present the performance indicators determined in December 1997 and in June 2001, which correspond to analyses done before and after the general track renewal, respectively between km 232 and km 265 of Northern Line, on Upward Track (*UT*) and on Downward Track (*DT*). The average values of the indicators are determined over 250 m intervals. In order to simplify the graph only one point, located in the middle of the interval, is represented.

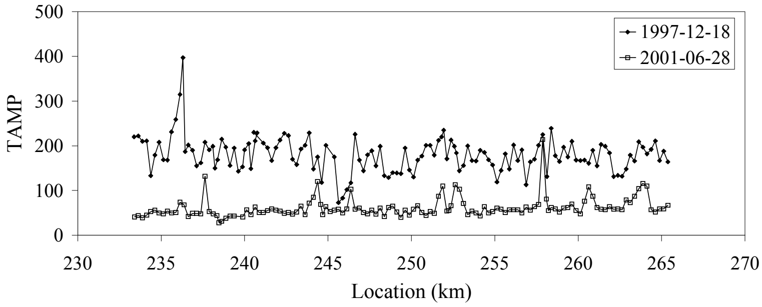
The indicators obtained in 1997 were generally determined for the circulation speed of 140 km/h, except as regards *DT*, between km 244 and km 264, in which they were determined for 100 km/h, because the circulation was limited to that speed. That procedure led to the fact that, in average, the values of the indicators regarding that section were less than the others, which does not implicate a better absolute quality of the track, taking into account the way these indicators are determined. The indicators obtained in 2001 were generally determined for the speed of 220 km/h.

The analysis of the presented elements makes it possible to conclude that there is a significant contrast between the values obtained for the performance indicators before and after track renewal, even by taking into account that these were determined for very different speed.

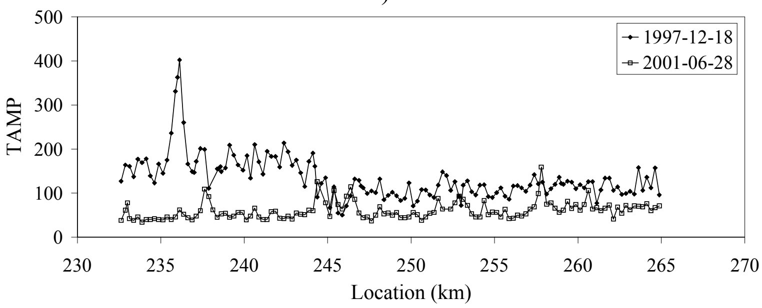
In December 1997, the majority of monitored sites of *UT* showed fairly low quality levels, which were represented by comparatively high performance indicators. The values of the Track Quality Index (TQI) ranged from “Poor” to “Defective”. That index only reached the “Acceptable” level in some particular cases.

As regards the same *DT* section, in 1997, it was possible to observe two fairly distinct situations: i) between km 232 and km 244, where the indicators were calculated for a circulation speed of 140 km/h, the *TQI* was generally higher than 200, which indicates a “Defective” or “Poor” quality level; ii) between km 244 and km 264, where the indicators were calculated for a circulation speed of 100 km/h, as previously mentioned, the *TQI* values were in general less than 200, but were generally higher than 150, which represents a track quality ranging from “Acceptable” to “Good”.

Reference must be made that records obtained in 1997 indicate some located sections with better quality. This can be explained by the fact that in some of these stretches ballast, sleepers and rails had already been changed. For instance, between km 257.823 and km 258.266 of the *UT*, where the former procedure was made about six months before the evaluation, the section identified in km 258.125 presented an “Acceptable” quality level. However, in these cases, only quality levels below the level “Good” (*TQI* >150) were reached, due to the lack of an adequate and systematic renewal of the platform.

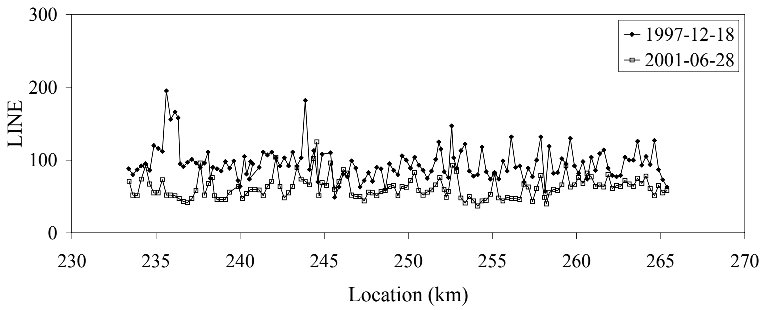


a)

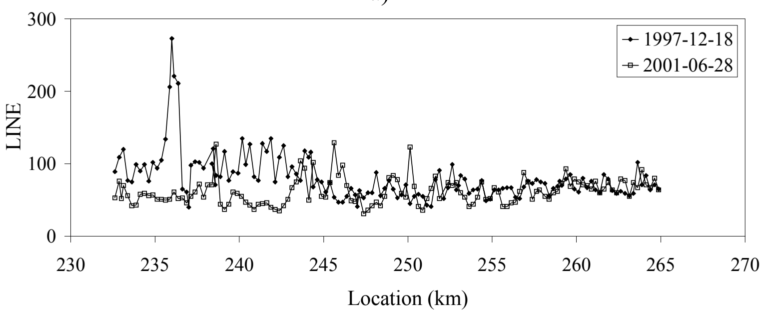


b)

Figure 3 – Performance indicators before and after renewal - TAMP a) *UT*; b) *DT*

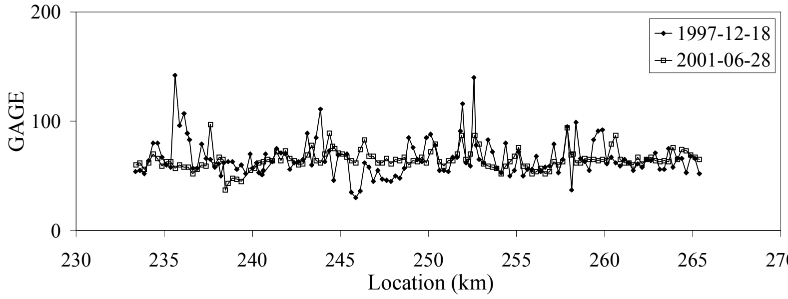


a)

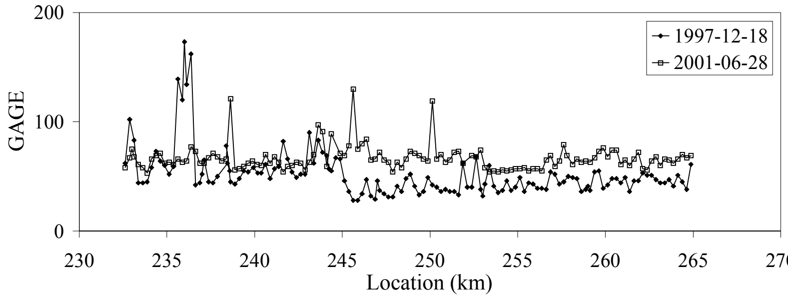


b)

Figure 4 – Performance indicators before and after renewal - LINE: a) *UT*; b) *DT*

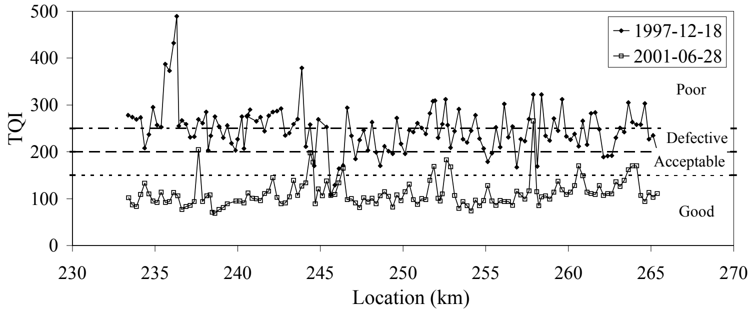


a)

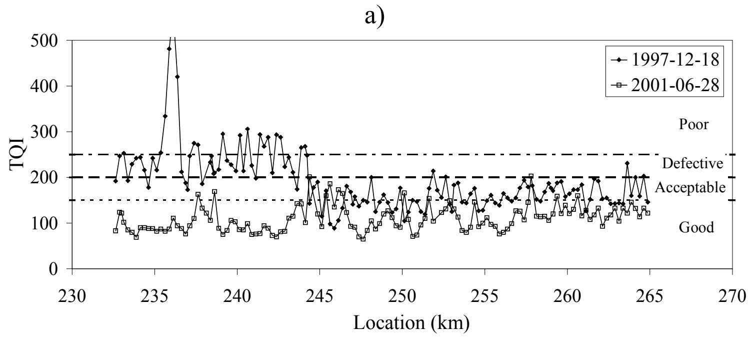


b)

Figure 5 – Performance indicators before and after renewal - GAGE a) *UT*; b) *DT*



a)



b)

Figure 6 – Performance indicators before and after renewal - TQI: a) *UT*; b) *DT*

In general, the values of the indicators obtained in 2001, after the renewal of platform, are fairly low. The *TQI* was generally less than 150, which represents a “Good” track quality level. Nevertheless, even after the renewal of the platform, some zones have exhibited a few disturbances, shortly after that renewal. Those sections are usually track singularities, namely the zones of track switches and level crossings, that had not yet been renewed, as well as under-crossings.

Table 3 presents the average values and the standard deviations of the distributions of the performance indicators obtained in 1997 and 2001, on the Upward Track. The mean values obtained in 2001 are much lower than those obtained in 1997. That difference would be even higher if the same reference speed had been adopted for the calculation of those indicators, in both periods, which would illustrate, in a more direct way, the absolute improvement in the track quality, after platform renewal. However, from the point of view of operation, it seems that it is more adequate to consider the values of the allowable speed in each condition.

Table 3 Performance indicators of the Upward Track

Performance indicators	**Average**		**Standard deviation**	
	1997	**2001**	**1997**	**2001**
Levelling (TAMP)	180	61	40	23
Alignment (LINE)	96	62	23	15
Gauge (GAGE)	66	65	17	9
Overall (TQI)	248	111	51	29

The values of the standard deviation of the indicators are also significantly different, which denotes a higher homogeneity in the geometric parameters of the track in 2001.

Then, it can be concluded that the track condition – considering the geometric characteristics – was much better in 2001, for more demanding conditions, than it was in 1997.

By taking into account the definition of each index (see §2), the index that can be best co-related with the quality of the platform is the Levelling Quality Index (TAMP). The comparison between the values obtained in the two campaigns makes it possible to conclude that this index was the one presenting a greater difference in the mean values (about 66%).

The Gauge Quality Index (GAGE), which is assumed the less influenced by the quality of the platform because it mainly depends on the superstructure, was the one presenting less variation (about 2%).

The overall analysis of results makes it possible to conclude that the renewed track zones, without an adequate platform treatment, have shown, within short term, quality levels that were normally above the “Acceptable” level, but were mostly below the “Good” level.

The sections where the renewal of the platform was performed generally presented TQI values less than 150 corresponding to a “Good” quality level.

Thus, the importance of having a good platform to obtain an adequate track performance has been demonstrated, as well as the validity of the implemented methodology, with the purpose of providing a platform with high quality standards.

4. CONCLUSIONS

The analysis of results obtained by the Track Inspection Vehicle, in two different periods (1997 and 2001), made it possible to conclude that the performance indicators obtained from geometric parameters have significantly improved after the renewal of the platform, particularly, the Levelling Quality Index.

The relation between the track quality levels obtained before and after renewal, is one of the most important indicators of the appropriateness of the renewal strategy implemented, in order to obtain the established objectives.

REFERENCES

FORTUNATO, E.; PINELO, A.; MATEUS DA SILVA, J. (2001) – "The strengthening and up grade of railway infrastructures. Geotechnical aspects". *Proc. XVth International Conference on Soil Mechanics and Geotechnical Engineering*. Istambul, Turkey, pp. 2069-2072.

FORTUNATO, E. (2005) – *Renewal of Railway Platforms. Studies about Bearing Capacity*. Ph.D. Thesis. University of Porto, Portugal (in Portuguese).

JOVANOVIC, S.; ZAALBERG, H. (2000) – "ECOTRACK: two Years of Experience", Rail International, April, pp. 2-8.

LABORATOIRE CENTRAL DES PONTS ET CHAUSSÉES (LCPC) (1973). Essai à la plaque. Mode opératoire CT-2.

RIVIER, R. E. (1998). "ECOTRACK: a tool for track maintenance and renewal managers." *COMPRAIL* 98: Computer Aided Design, Manufacture and Operation in the Railway and other Advances Mass Transit System. Lisbon, Portugal.

UNION INTERNATIONALE DES CHEMINS DE FER (UIC) (1994). *Ouvrages en terre et couches d'assise ferroviaires*. Code UIC 719R, 2émé édition.

ACKNOWLEDGMENTS

The financial support of project "POCI/ECM/61114/2004- Interaction soil-railway track for high speed trains" from *Fundação para a Ciência e a Tecnologia* is acknowledged.