Janusz Madejski, GRAW, Silesian University of Technology, Gliwice, Poland
Juliusz Grabczyk, GRAW, Gliwice, Poland

Continuous geometry measurement for diagnostics of tracks and switches

Abstract

The paper presents issues connected with track and switch geometry condition assessment. Philosophy of track line-speed dependent geometry parameters is explained and methods of assessment of the more generalized track condition evaluation in the form of synthetic quality coefficients is described. Requirements for geometry data collection are discussed and relevant needed equipment design features are presented. Analysis of the temporal trend of the track and switch geometry change calls for measurement data storage and analysis. Relevant database software system is described along with examples of queries. Real life examples and experience with this methodology of track and switch geometry parameters analysis in Poland are presented. Track geometry parameters database systems are presented along with the synthetic coefficients processing and use for diagnostic reasoning.

1. Introduction

It would be best to build a railroad in a straight line, over level ground, between big commercial centres. In real life, one has to face the terrain to be traversed, balancing the cost of construction against the maintenance and operating costs. Therefore, where justified, the railroads are generally built for heavy duty operation, with minimum grades and curvature, with heavy bridges, and multiple tracks. In some situations where track maintenance is cumbersome, ballast and sleepers are replaced by the continuous reinforced concrete support of the rails, however the resulting reduction of maintenance costs is offset by higher construction and renewal costs.

Track geometry measurements are made using the manual tools, microprocessor based portable instruments, and geometry cars. However, any measurement method or tool without data logging feature, makes it virtually impossible to collect all data that would be necessary for the detailed diagnostic reasoning on a line or railway network level, being useful only for direct measurement of some track parameter in a particular point. Determining of the permanent way with the continuous design and maintenance characteristics is possible if it is measured on the minimum 200-300 m length with the measurement steps of ca 0.5 m [1].

Microprocessor base track gauges or self-propelled geometry cars, or else the ones coupled into regular trains, can record all aspects of track alignment and riding quality on plots and tabular reports, so that maintenance service can locate the specific locations needing maintenance. The first archetypes of today's geometry cars were designed by Dorpmüller (1885), Dolgov (1910), and Proxima (1912) [1].

An important issue has been how to evaluate track condition basing on the measurement of its geometry. In each case, for any geometrical parameter of the track some assessment has to be carried out. The simplest synthetic assessment referring to a single geometrical parameter of the track, e.g., its gauge, are its average and standard deviation values. The range of values is an even simpler measure, that, however, should not be used for a set of more than 20 readings. Closer analyses based on actual readings and experience in operating trains have revealed that standard deviation values of about 1.0 mm indicate to the very good condition of the track, whereas its value exceeding 3.5 mm is characteristic for bad track condition and may cause uneven running of the train at speeds as low as 100 km/h.

Track gauge measured 14 mm below the rail running surface rails features one of the fundamental geometrical parameters of the track. It turns out that even at the 40-50 Tg load per year measurements made with the geometry cars twice a year – in Spring and in Autumn – give enough diagnostic information about the track gauge, provided the sleepers or elements fixing the rails to them are not in a very bad condition. The expected track gauge increase is about 2 mm for the straight tracks and curves with radii down to 700 m subjected to 20 Tg load.

Track twist may be measured using one reference length and then re-calculated to another length – in this way microprocessor track gauges with body length of 1 m can measure twist on base lengths as big as 5 m or 6 m. The main reason for diagnostics taking into account twist has been introducing heavy cars with high torsional rigidity so in some cases twist as low as 4‰ (20 mm per 5 m base) may turn out to be unsafe. All allowable deviations of the track structure are specified taking into account evenness of running. Nevertheless, fast passenger lines allow even larger twist than low speed cargo lines.

Each horizontal irregularity of the track curvature results in acceleration of the train traveling through it. Local curvatures of the straight track also affect normal train movement. Therefore, in both cases horizontal irregularities deteriorate ride quality. Horizontal irregularities tend to grow intensively after reaching certain value. Therefore, horizontal irregularities are very important in track diagnostics, the more so as the line speeds are increased. For example, the allowable differences of versed sine measured for the 20m long chord are 8 mm for speeds up to 120 km/h, 6 mm for speeds up to 140 km/h, and 4 mm for speeds above 140 km/h, for transient curves these differences are 6.4 and 3 mm. It is important to note that the smallest practically feasible accuracy of track location in horizontal plane is not much more accurate, therefore, accuracy of the technological process features an important factor for line speeds of 120 km/h and more.

Any assessment of the track condition based on one geometrical parameter only is incomplete, therefore more parameters are used to characterize track condition [2]. Therefore, much work has been done to work out formulae that would reliably take into account various track geometrical parameters affecting the train ride quality and safety. Synthetic methods of the geometrical assessment of track condition can be divided into three groups:

- methods based on values of the geometrical parameters measured at a particular point
- methods using the synthetic assessment of the geometrical parameters measured continuously along the track
- methods of the indirect assessment in which the geometrical parameters of the track feature only one of the main factors influencing the final assessment coefficient.

The synthetic coefficient may be evaluated by:

- counting the wrong values in a given number of classes, using certain weights
- statistical methods
- spectral analysis methods.

Long time research and maintenance experience of Polish State Railways has been implemented in the form of an instruction, governing what parameters and how should be measured for reliable valuation of the track condition [3].

2. Synthetic assessment of track condition according to Polish regulations [8]

The Polish PKP D-75 Instruction aims at determination of uniform principles for:

1. measurements of track geometry by means of manual measuring equipment,
2. measuring of the track geometry of tracks on the Polish State Railways (PKP) network with geometry cars and electronic track gauges,
3. technical examination of tracks and switches carried out by workers of line supervision of road service
4. evaluation of track maintenance condition.

The measurements and examinations of maintenance condition of tracks are intended for revealing the defects and irregularities that occur in tracks and for making synthetic evaluations of track condition. The resulting assessment should is used for planning track repairs and to analyse the condition of track maintenance quality on particular lines. Defects hazardous to traffic safety should be removed immediately.

Table 1 Frequency of measurements

Line speed [km/h]	Required measurements per year	Remarks
v ≥ 160	4	every quarter
100 ≤ v < 160	2	in Spring and Autumn
v < 100	1	in Spring

In addition, frequency of measuring track geometry, along with measurements of track wear on line sections that contain curves, should be carried out as follows:

- twice a year (spring and autumn) – tracks within curves 350 ≤ R ≤ 500m,
- three times every four months a year – tracks in curves of R < 350m.

Measurements can be performed by means of:

- measuring vehicles,
- microprocessor track gauges,
- universal manual track gauges,
- rail profilometers.

Table 2 Groups of track geometrical parameters

Group of geometrical parameters	Parameter definion
Vertical	◦ The difference in height of the rail-series is named *cant*. ◦ *Twist of track* is a difference in cant values of track rails over the length of 5m. ◦ *Irregularities of track rails in the vertical plane for left or right hand rails* - a vertical rail deviation measured on the rolling surface from datum line which is provided by a 10 m long chord.
Horizontal	◦ *Track gauge* is a distance between inner surfaces of rails which is measured 14 mm below their rolling surface ◦ *Gradient of track gauge* is an additional, secondary parameter of railway track. It determines an increase in width on a measuring base which amounts to 1 m base as standard. ◦ *Irregularities of rails in horizontal plane* determined by measuring horizontal deflection of track on 10 m basis for each track rail separately.

According to the Polish D-75 Instruction measurements are taken by geometry cars or portable measuring instruments. Polish State Railways (PKP) operate two EM-120 and one WPA-50 geometry cars. Their measurement systems make it possible measure all basic parameters of track geometry (see Table 2), automatic recording and analysis of results of measurement. These results are presented in a form of diagrams, tabular statement of existing defects and the synthetic evaluations regarding the track maintenance condition. The geometry cars are operated by the Centre for Diagnostics and Track Welding Technology in Warsaw, hereinafter called DBT.

2.1 Threshold analysis of geometric parameters of track

In the process of threshold analysis, a comparison is made between the values of measurement signal and boundary values to find deviations in parameter value. The boundary values of individual parameters are tabulated separately for each of track classes. The relevant allowable deviations are specified in the regulations.

Three classes of deviations of parameter value are specified for each parameter – see fig.1. The A and B class deviations are only counted for statistic purposes. Class C deviations are called track defects and listed in the report. The 50% value of a class C deviation gives the class A deviation value, while 75% of class C is the class B deviation. Defects which exceed the C class boundaries by 25% are additionally marked with an asterisk "*".

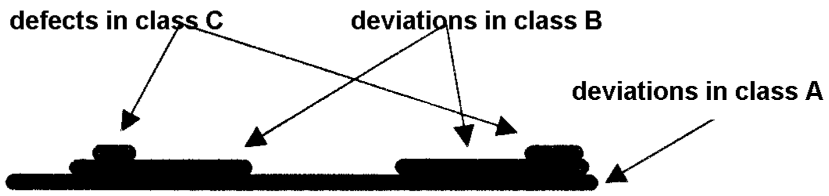

Fig.1 Bar chart showing deviations of track parameter values

2.2 Report format requirements

Measurement results are generated in two forms: graphical and tabular printouts. The tabular data is printed during the measurement and consist of the following report types:

- detailed reports: listing defects and characteristic points of line,
- statistical reports: with totals for all geometrical parameter types,
- synthetic reports: with standard deviations of all parameters and the synthetic assessment of the track condition.

All reports are made for the basic section of track which, as a standard, amounts to 1000m. Cumulative reports are available which containing data on a line section or entire line.
Plots of all measured track parameters printed in real time during the measurement include, apart from the representation of track parameters' values, also other additional information, like:

- hectometer markers,
- track number, class and line speed,

- curve markers,
- markers of certain objects, like semaphore, bridge or switch
- speed value
- bar chart indicating occurrences of deviations in classes A, B, C.

Each of the track parameter plot lines is surrounded by border lines of class C, while the numbers located within square brackets at the parameter name define the position of limits.

2.3 Synthetic evaluation of track maintenance condition

Standard deviations for each parameters have been accepted as a basic quality measure of track maintenance. Standard deviations are calculated using the formula :

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{i=1} - \overline{x}\right)^2}$$

where:

n - the number of signals registered on the analyzed track section,

x_i - value of parameter at point i,

$\overline{x}$ - average value of signal.

The synthetic track quality coefficient ***J*** provides a quantitative evaluation of track condition. This coefficient is calculated using the following formula:

$$J = \frac{S_z + S_y + S_w + 0.5 \cdot S_e}{3.5}$$

where:

S_z standard deviation of vertical irregularities

S_y standard deviation of horizontal irregularities

S_w standard deviation of track twist

S_e standard deviation of track gauge

Table 3 Allowable deviations of track geometrical parameters depending on line speed [8]

Speed	Irregularities		Twist	Deviations of rail gauge			Cant	J
	Horizontal	Vertical	On 5 m	Widening	Narrowing	Gradient		
Km/h	mm	mm	mm	mm	mm	mm	mm	mm
30	44	40	25	25	9	3	25	12.0
40	35	35	23	20	9	3	25	11.0
…	…	…	…	…	…	…	…	…
90	15	16	15	10	8	2	18	6.2
…	…	…	…	…	…	…	…	…
120	9	10	12	9	7	1	12	4.0
…	…	…	…	…	…	…	…	…
160	6	6	8	6	4	1	8	2.0
…	…	…	…	…	…	…	…	…
200	4	3	5	4	3	0,5	5	1.4

The table includes values of allowable deviations for class C for particular parameters.

2.4 Five parameter track defectiveness

Defectiveness of each of parameters on evaluated basic section is a ratio of length sum of sections of which acceptable deviation are exceeded to the total length of this section (fig.2). Defectiveness for each measured track parameter is calculated from the relation:

$$W = \frac{\sum_{i=1}^{n} l_i}{l}$$

where:

- n_p - number of samples of signals exceeding acceptable deviations on analyzed section,
- n -number of samples of signals on analyzed section.

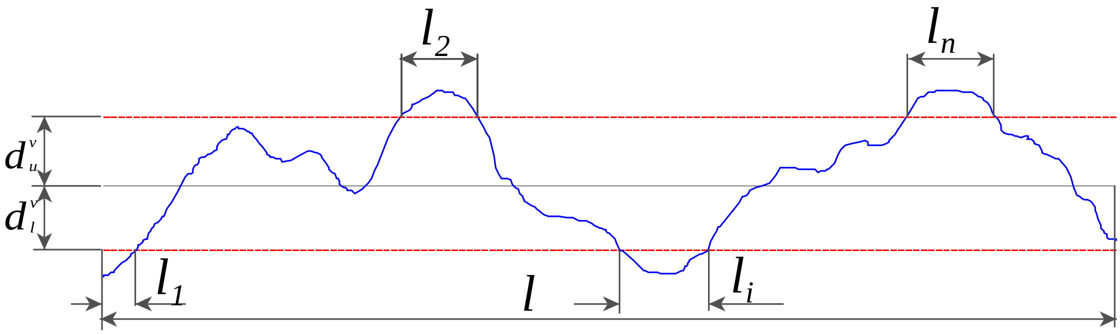

Fig.2 Selection of samples for evaluation of track defectiveness for a parameter

This method can be used both for the direct measurements and those made using the geometry cars. The very small correlation between values makes it possible to treat them as the independent events in practice. This attitude simplifies calculations without affecting the results. Therefore, from the probability theory we get:

$$P(A_1 \cup A_2 \cup \cdots A_n) = 1 - [1 - P(A_1)] \cdot [1 - P(A_2)] \ldots [1 - P(A_n)]$$

so the five parameter defectiveness is defined as:

$$W_5 = 1 - (1 - W_e)(1 - W_g)(1 - W_w)(1 - W_x)(1 - W_y)$$

where:

- W_e - defectiveness of track gauge,
- W_g - defectiveness of cant,
- W_w - defectiveness of twist,
- W_z, W_y - are arithmetic averages for vertical and horizontal irregularities, respectively, as determined from the defectiveness of left and right rails

The five-parameter defectiveness $\boldsymbol{W_5}$ provides a quality measure of line section maintenance. Qualification for line maintenance depending on the $\boldsymbol{W_5}$ defectiveness value is specified in the D-75 Instruction.

Table 4 Evaluation of track geometry condition basing on the five-parameter defectiveness $\boldsymbol{W_5}$

Evaluation of line	W_5 value
New lines	$W_5<0.1$
Lines in good condition	$W_5<0.2$
Lines in sufficient state	$W_5<0.6$
Lines indicating insufficient condition	$W_5>0.6$

Basing on measurement results DBT works out a cumulative statement of synthetic indices for track quality, ***J*** and $\boldsymbol{W_5}$, to evaluate the track condition on respective lines for District Headquarters and the respective Road Division. Upon termination of spring and autumn measurements, these statements should be worked out within a period of 20 days. Within 30 days from the measurement, Road Divisions send information (notification) to the Road Administration about removing defects of class C.

2.5 Formal requirements connected with measurements made with geometry cars

During measurements of track made with the geometry car, the following persons should be present on board, apart from the car operators:

1) representative of Chief Office for Maintenance of Railways on selected lines when necessary,
2) deputy general manager for maintenance and investments of the particular District Management of the State Railways – occasionally on selected lines,
3) head of road administration, or his deputy/senior inspector – when measurements are taken in their own area,
4) head or deputy head of road division (DO) during each measurement on his area
5) head of road section, hereinafter called (DS) for each measurement on his area.

Representatives of DO and DS should have measurement results from previous measurements with them: graphical and tabular printouts. During analyzing the measurement, DS explains the course of removal of defects within class C to the head of administration or division. The representative of rail network administration who participates in measurement is obliged to check elimination of class C defects revealed during former measurement, and in case they occur again, to demand comments upon such circumstance from the head of road division.

In case of doubts connected with the credibility of measurement at the actual state of track geometry, the representatives of line supervision being present during the measurements should notify such reservations to the geometry car operators and ask them to repeat the measurement.

Upon termination of track measurement, the head of road division or his or her deputy participating in measurements, obtains the copies of the graphical and tabular measurement reports from the geometry car supervisor, confirming this fact in the „Measurement results log book”. Having received measurement results, on the next day and in the presence of road inspector concerned, he analyses the measurement results to specify the plan for rectifying the C class defects. The analysis result, along with decision regarding the necessary improvements should be noted down on the copy of measurement results, and forwarded to DS within three days from the measurement date.

3 Track geometry data collection

3.1 Track gauges

An example of the microprocessor based track gauges is the device made by GRAW [9] - Track Gauge TEC-1435. Low weight (about 20 kg) makes fast removal from the track possible to let the train pass, next, immediate continuation of the measurements is possible without any calibration. The gauge’s electronic memory can store about 15 km of the track length measurement results, which is equivalent to the single shift measuring capability of the gauge. The device readings are recorded automatically in its electronic memory in real time, as the trolley travels along the track. The operator can see the measured values of the track gauge, cant, and the actual mileage on the display during the measurements. The large size foil keyboard makes it possible to enter information on track faults found. One can mark locations, e.g., of the broken weld or rail, the need to replace the sleeper or missing bolts. The device can measure: track gauge [1420÷1485 mm], track cant [±200 mm], vertical irregularities [±4 mm/1 m], horizontal irregularities [±5 mm/1 m] with the mileage increments of 0.5 m.

Software for the PC platform, supplied with the track gauge makes it possible, among others, calculation of the track gauge gradient, track twist, and recalculation of the measured vertical and horizontal irregularities to 10 m long chords. Tabular printout of the measurement results is possible, with marking the mileage values where faults observed by the operator occurred, printout of the measurement results as plots, and also calculation of the synthetic indices according to regulations of the Polish State Railways, Hungarian State Railways or Dutch Railways – for evaluation of the track geometry quality – see figs 3÷5. The main advantage of the TEC-1435 track gauge system is its capability for evaluation and visualization the measurement results in a way similar to the one employed by geometry vehicles.

3.2 Geometry cars

All real-time data acquisition and further signal processing must recognize the elementary distance increments as small as 0.25m with parameters' accuracies of about 0.1mm [4]. To this end many systems have been developed - most sophisticated of them are the track geometry cars carrying out their measurements at speeds up to 250 km/h [5]. However, track

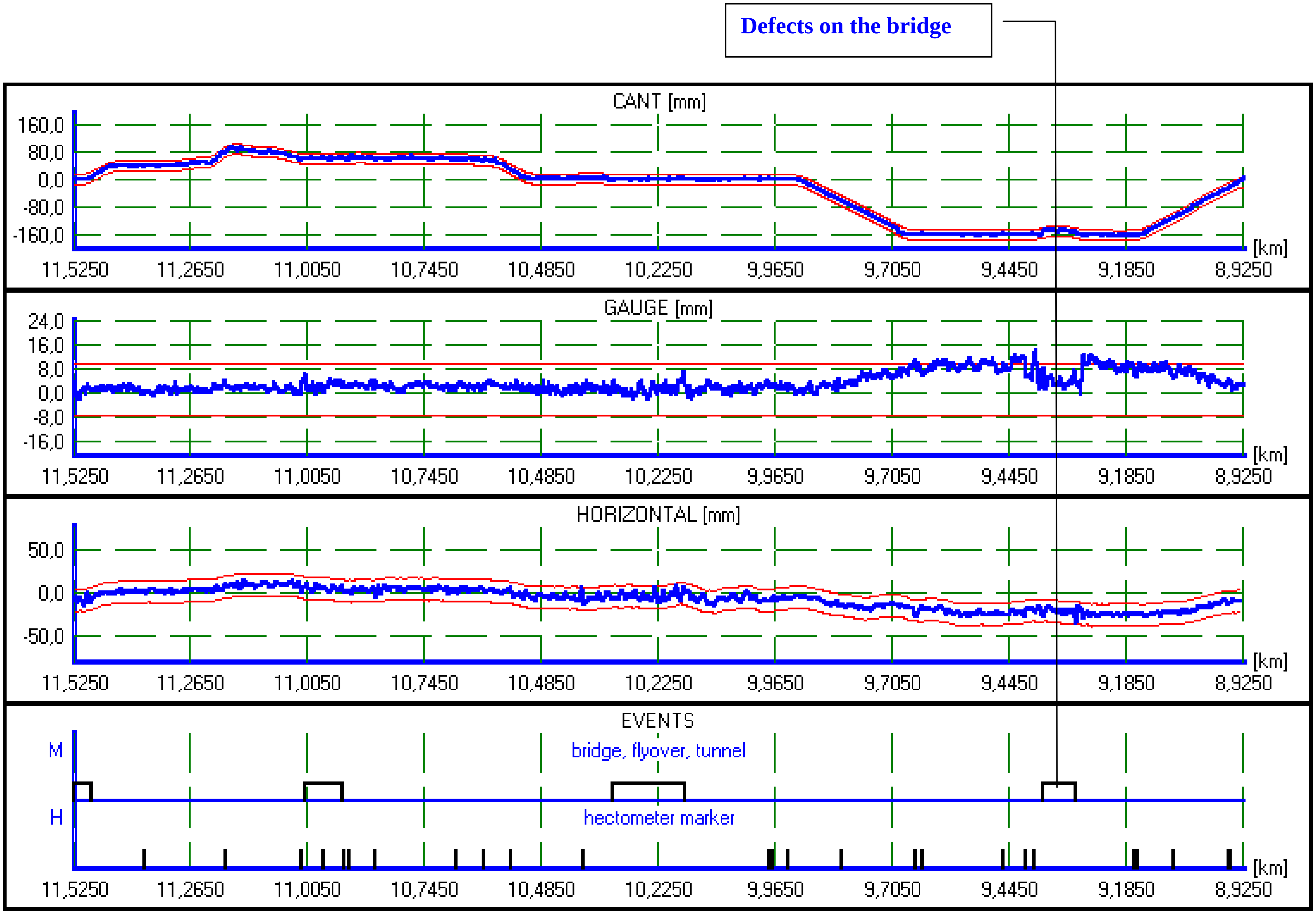

Fig.3 Exemplary plot of graphical parameters of the track – deteriorated track gauge and cant are clearly visible at the bridge

Page 1
Measurement data file of: 07.06.1999r., Route: SZO-GL23 OD R3, Track no: 1

Tolerances: -8,0 mm < Gauge < 10,0 mm
-2,0 mm < Gradient < 2,0 mm
-18,0 mm < Cant < 18,0 mm
-3,0‰ < Twist < 3,0‰
-16,0 mm < Vertical < 16,0 mm
-15,0 mm < Horizontal<15,0 mm

Events and defects filter: HMRDEFBPWLS)Y/Z;

H - hectometer marker
M - bridge, flyover, tunnel
R - crossover
D - crossing
E - platform
F - precise measurement
B - sleeper fixing bolts missing
P - broken rail
W - sleeper replacement necessary
L - fish bar bolts missing
S - flash
) - rail's flat
Y - burr
/ - skewed sleepers
Z - side wear
; - broken weld joint

KILOMETER [km]	GAUGE [mm]	GRADIENT [mm]	CANT [mm]	TWIST [‰]	VERTICAL [mm]	HORIZONTAL [mm]	DEFECTS HMRDEFBPWLS)Y/Z;
28,6800	-5,8	---	2,4	---	---	---	
28,6750	-7,1	1,3	2,3	0,0	-3,0	-198,5	
# 28,6745	-8,5 #	1,9	2,3	0,0	-2,7	-197,3	
# 28,6740	-9,4 #	2,3 #	1,9	0,1	-2,7	-196,7	
# 28,6735	-9,3 #	0,8	2,2	0,1	-2,6	-196,1	H
……………							
28,6700	-7,0	-0,7	1,1	0,2	-5,1	-194,2	F
28,6650	-1,3	-0,0	4,1	-0,6	5,0	-195,2	F
28,6600	-1,8	-1,7	3,4	0,2	1,2	-194,6	
28,6550	-2,7	0,3	4,4	-0,2	-4,3	-191,4	
# 28,6525	-3,6	-0,0	5,4	-0,6	-9,7	-189,1	
# 28,6510	-2,1	-1,5	3,5	-0,1	-1,4	-186,3	
…………..							

Fig.4 Fragment of an exemplary listing of digital results of the track geometry measurements made with the TEC-1435 track gauge

Page 1
Measurement data file of: 07.06.1999r., Route: SZO-GL23 OD R3, Track no: 1
Synthetic assessment of track condition calculated for 100 [m]

Coefficient J limit: 6,2

		Standard deviation							Quality levels						
Section		CoeffJ	Gauge	Grad.	Cant	Twist	Vert	Horiz	Gauge	Grad	Cant	Twist	Vert	Horiz	5-elem
28,6800	28,6000	3.6	1.8	0.9	1.1	1.6	3.1	6.8	0.04	0.01	0.00	0.00	0.00	0.00	0.04
28,6000	28,5000	2.5	1.2	0.7	10.3	3.3	2.9	2.1	0.00	0.01	0.00	0.00	0.00	0.00	0.00
28,5000	28,4000	1.9	1.0	0.9	3.8	2.2	2.4	1.5	0.00	0.02	0.00	0.00	0.00	0.00	0.00
28,4000	28,3000	2.3	1.2	0.8	6.5	2.3	3.6	1.6	0.01	0.01	0.00	0.00	0.00	0.00	0.01
28,3000	28,2000	2.8	2.9	1.0	5.6	2.3	4.3	1.9	0.29	0.04	0.00	0.00	0.00	0.00	0.29
28,2000	28,1985	0.3	0.2	0.3	0.4	0.9	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Fig.5 Exemplary synthetic assessment of track condition generated by TEC-1435 software

condition may be evaluated reliably only using data gathered from multiple sources like real-time data acquisition and processing systems as well as at least visual inspection.

Database of measurement results may store in a proprietary format either the calculated track parameters only, or the full record of all sensor signals which makes it possible to carry out further off-line analyses of the track at a later time. Graphical output of seven values is produced in real time by the system). These may include any combination of calculated parameters and raw signal values - at user's discretion.

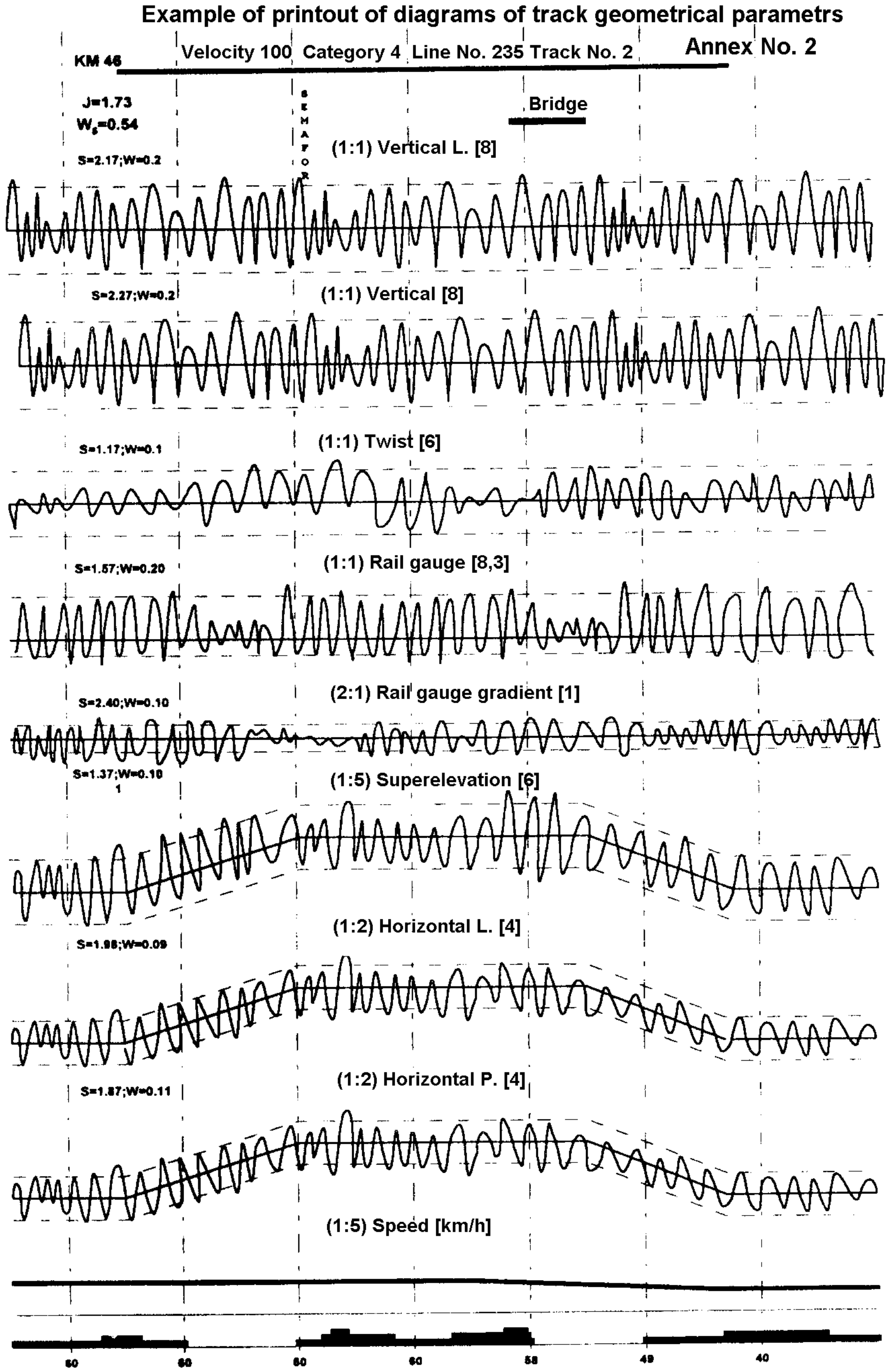

Fig.6 Exemplary format of the graphical measurement report generated by geometry car

Multiple analysis parameters supplied to the system by the operator include the standard reference length (usually 1000m) used for evaluation of track condition, data used for automatic track curve detection, etc. Output files produced by the system are stored in an external archive, they are also used as data for expert systems supervising the track life history and determining service time increments. The track geometry documentation generated by the system is a basic source of information in case of any track operation problems arising. Safe keeping of this data is required by the railway regulations. All this information is stored in a dedicated database system that enables the user to simulate any test runs performed and replay them to reclassify the track with the changed quality level requirements. In addition to graphical printouts (fig.6), output data files there have five main summary listings' formats (fig.7) [10]:

- listing of all detected excessive values of analysed geometrical track parameters,
- summary listing with analysis of the basic track section,
- summary listing with analysis of the line section,
- summary listing with analysis of the entire line,
- synthetic report on the line quality.

```
***  Pojazd EM-120 JAZDA POMIAROWA       z dnia 20.06.1997  godz: 11:00:15  ***
================================================================================
Orientacja pojazdu: L=P                     Pulpit aktywny: Przedni
       Lokalizacja:  12.211km         Predkosc maksymalna: 100km/h
        Numer toru:  2                       Data aktualna: 20.06.1997r.
   Krok_skanowania:  250mm                 Data kalibracji: 20.06.1997r.
       Numer linii: 134

 L I N I A: Jaworzno Szczakowa - Myslowice
   ODCINEK: Myslowice - Jaworzno Szczakowa
Wlasciciel: DBT Warszawa ul.Chodakowska 50
  Dyrekcja: Slaska

Report of local defects with event/object log.
================================================================================
PARAMETR/OBIEKT   KM/M    KM/M       DL    MAX     NA METRZE  WD      K  KD    VD L
1                  2       3          4     5       6          7       8  9    10 11
The report columns contain the following information:

1. PARAMETR/OBIEKT – name of the parameter or object:
Parameters:
POSZERZENIE   – TRACK WIDENING
ZWEZENIE      – TRACK NARROWING
PRZECHYLKA    - CANT
WICHROWATOSC  – TWIST
POZIOME L.-   (L – lewy TOK) – HORIZONTAL L.  (L – left RAIL)
POZIOME P.-   (P – prawy TOK) – HORIZONTAL R. (R – right RAIL)
PIONOWE L.-   (L – lewy tok) – VERTICAL L.    (L – left RAIL)
POZIOME P.-   (P – prawy tok) – VERTICAL R.   (R – right RAIL)
GRADIENT SZER. – TRACK GAUGE GRADIENT

Events and objects:
PROSTA       – beginning of the straight section of the track
LUK          – beginning of the curve in the track
ROZJAZD      - SWITCH
PRZEJAZD     - CROSSING
MOST         - BRIDGE
SEMAFOR      – SIGNAL
```

2. KM/M – beginning of the defect or event
Other columns are not filled in when the track changes from the straight section to the curve and vice versa.

3. KM/M – end of the defect or event

4. DL – length of the defect or event

Next columns are filled in only for defects.

5. MAX – maximum defect value logged
6. NA METRZE – odometer reading for the maximum defect value (kilometer value is neglected)
7. WD – allowable value resulting from the set of limits employed for analysis
8. K – class of the set of limits. In Poland, sets of limits are assigned classes in addition to speed. We do not know why this is so, as it is simply redundancy. It was left, perhaps, due to some old solutions. The higher is the class, the higher the line speed is.
9. KD – the number of the first class, for which there would be no overshoot. If an overshoot occurs for all defined classes then ^ character is inserted.
10. VD – maximum speed complying the class from the KD column. If there is no class, then @ character is inserted.
11. L – location of the defect or event: L – curve, P – straight
*For each parameter and each class four limit levels are defined: A, B, C i D. Level C is used for analysis of defectiveness. Levels A and B, lower than the defective level, are used for statistical purposes. Level D is the level higher than C and treated as the dangerous level. Exceeding the D level is signalled by * character at the end of line. (Please advise us if you need more detailed explanations – we will send you then the relevant fragment of the geometry car software design requirements).*

LUK	12.210									
POSZERZENIE	12.202	12.173	30m	11mm	188m	10mm	9	6	70	L
PRZECHYLKA	12.202	12.092	110m	24mm	181m	15mm	9	5	60	L*
POZIOME L.	12.095	12.087	9m	14mm	90m	13mm	9	8	90	L
POZIOME P.	12.096	12.087	9m	13mm	90m	13mm	9	8	90	L
WICHROWATOSC L.	12.108	12.087	22m	18mm	94m	14mm	9	6	70	L*
POSZERZENIE	12.160	12.087	73m	17mm	123m	10mm	9	4	50	L*
GRADIENT SZER.	12.207	12.088	120m	5mm	128m	2mm	9	^	@	L*
PROSTA	12.086									
LUK	12.061									
ROZJAZD	12.086	12.054	32m							
PIONOWE P.	12.086	12.055	31m	18mm	67m	14mm	9	6	70	L*
POZIOME L.	12.086	12.054	32m	24mm	58m	13mm	9	4	50	L*
POZIOME P.	12.059	12.054	5m	32mm	54m	13mm	9	3	40	L*

....

WICHROWATOSC L.	6	3	20	2	38	3	5.78	0.04
POSZERZENIE	0	0	6	2	177	6	-	0.21
ZWEZENIE	1	1	2	1	3	1	-	0.01
GRADIENT SZER.	0	0	0	0	204	7	-	0.31
SUMA	65	16	98	16	764	35	7.67	0.54

The columns contain:
PARAMETR – parameter name
(A) – total length of overshoots above the A level, but without exceeding the B level. The neighbouring column EX contains the number of overshoots
(B) – total length of overshoots over the B level, but without exceeding the C level. The neighbouring column EX contains the number of overshoots
(C) – total length of overshoots. The neighbouring column EX contains the number of overshoots
S – standard deviation value calculated for the analysed track section. The J coefficient is given in the closing row.
W – value of the parameter defectiveness, calculated for the analysed track section. The W5 coefficient is given in the closing row.

At the end of analysis the same summing up is made for the line sections and lines (routes) – these are the organisational units in Poland.
Suuming up is done for each set of limits separately if they were changed during the car movement (consecutive track sections may be analysed using different sets of limits). Moreover, separate summing up are made for the straight track sections

and for its curves. These tables are at the end of this report. Meaning of the columns are the same as for the track section summary table.

ROZJAZD	12.005	11.988	17m						
GRADIENT SZER.	11.999	11.988	12m	9mm	992m	2mm	9	^	@ P*
PIONOWE P.	11.987	11.978	9m	15mm	981m	14mm	9	8	90 P
POSZERZENIE	11.988	11.980	8m	12mm	980m	10mm	9	5	60 P*
GRADIENT SZER.	11.988	11.976	11m	9mm	979m	2mm	9	^	@ P*
LUK	11.976								
MOST	11.973	11.969	4m						
PIONOWE P.	11.976	11.970	5m	15mm	972m	14mm	9	8	90 L
POZIOME L.	11.976	11.969	7m	27mm	970m	13mm	9	4	50 L*
POZIOME P.	11.976	11.969	7m	20mm	969m	13mm	9	5	60 L*
WICHROWATOSC L.	11.976	11.969	7m	16mm	970m	14mm	9	7	80 L
GRADIENT SZER.	11.976	11.971	5m	6mm	976m	2mm	9	^	@ L*
ROZJAZD	11.969	11.950	19m						

Fig.7 Fragments of the exemplary printouts from the geometry car measurements

4. Integration of diagnostic data from different sources

Full use of the diagnostic information collected using geometry cars and track gauges may be attained when all these measurement results are stored in their database systems [7]. Figure 8 shows a concept of the integrated track diagnostics databases – the blue line indicates the “fast lane” of introducing the digital form of geometry car readings into diagnostic practice. These systems contain source data for all types of diagnostic track data analyses, including analysis of trends of particular parameters and changes in synthetic parameters describing track condition.

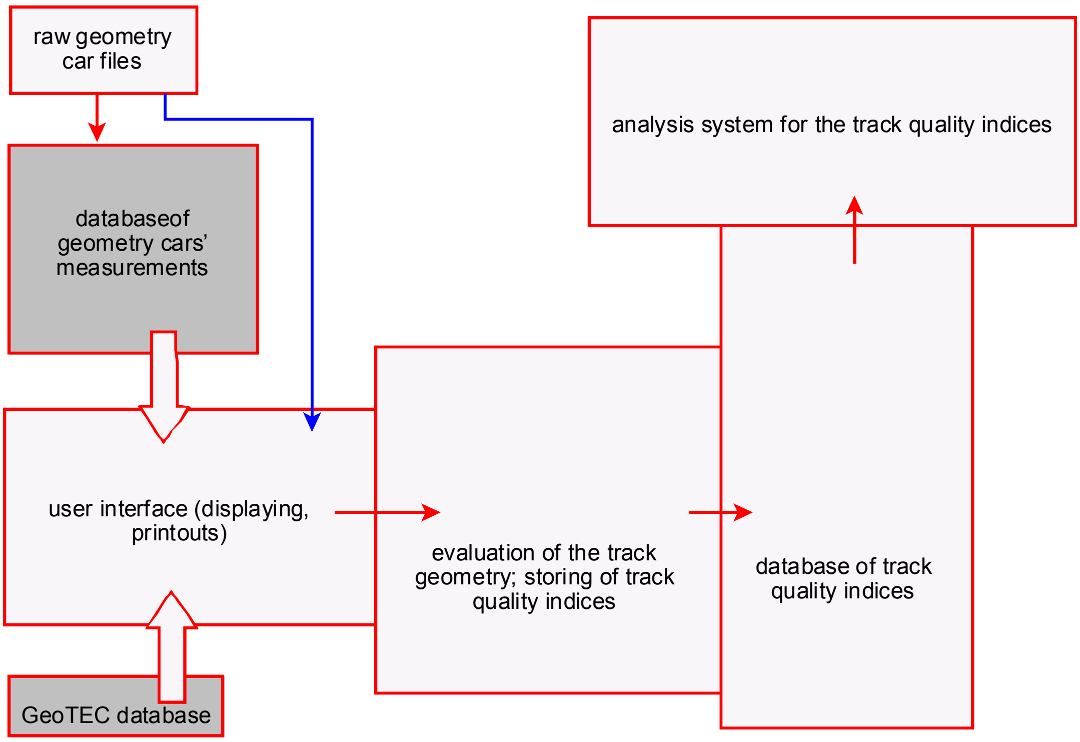

Fig.8 Integration of data coming from various track geometry measurement systems

4.1 GeoTEC database

This database has been developed for storing data about the track condition, collected using the microprocessor based track gauges. The system consists of two subsystems: database with a model of the railway network model, and the database with the measurement results. An important feature of this database is its capability of storing the real track geometry measurement results along with its design specification, so comparison of the actual track geometry and the theoretical one is possible. Moreover, it is possible to compare many "historical" readings of the track to detect the rate of its deterioration in terms of particular parameters and/or the track synthetic quality coefficients. All measurement results acquired using track gauges are preprocessed before storing in the database, so that diagnostic analyses do not require the user to look for any specific readings.

An example of the GeoTEC potential is illustrated in fig.9 and fig.10 in which measurement results are shown for a Dutch railway line before tamping, immediately after tamping, and two weeks later – after stabilizing the track. Changing values of the synthetic J coefficient and other synthetic values are shown in fig.9. In fig.10 a closer analysis of the cant plot reveals the error made during tamping (13.094 km) where the track was tamped excessively and the rail was bent upwards. After two weeks of operation it came down to the "standard" location – this place, especially the substructure, should be closely checked, as there is a threat of rail defect in near future.

Page 1 of 1

Volker Stevin Rail & Traffic

Begin route: Xxxxxx
Synthetic assessment of track condition calculated for 200 [m]

Limiting J coefficient: 4.0

			Standard deviations							Quality levels					
Section km]	Time	Coef J	Gauge	Grad	Cant	Twist	Vert.	Horiz.	W5	Gauge	Grad	Cant	Twist	Vert.	Horiz.
14.490 14.600	25.10.2001	1.7	0.56	0.33	0.99	1.50	2.20	1.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	08.10.2001	4.8#	0.54	0.31	2.15	2.96	1.80	11.62	0.40	0.00	0.00	0.00	0.00	0.00	0.40
	03.10.2001	19.0#	0.56	0.32	1.46	2.14	2.26	61.95	0.32	0.00	0.00	0.00	0.00	0.00	0.32
14.600 14.800	25.10.2001	1.4	0.62	0.36	1.02	1.52	1.57	1.65	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	08.10.2001	4.6#	0.60	0.34	1.81	2.41	1.40	11.95	0.28	0.00	0.01	0.00	0.00	0.00	0.28
	03.10.2001	5.5#	0.61	0.34	1.19	1.73	1.75	15.32	0.08	0.00	0.01	0.00	0.00	0.00	0.09
14.800 15.000	25.10.2001	1.8	0.47	0.30	1.51	1.80	2.19	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	08.10.2001	2.3	0.47	0.30	1.67	2.14	2.03	3.69	0.03	0.00	0.00	0.00	0.00	0.00	0.03
	03.10.2001	3.0	0.46	0.29	1.64	2.06	2.13	6.07	0.06	0.00	0.00	0.00	0.00	0.00	0.06
15.000 15.200	25.10.2001	1.9	0.53	0.37	1.30	1.69	2.83	1.89	0.03	0.00	0.00	0.00	0.00	0.03	0.00
	08.10.2001	2.4	0.52	0.36	1.79	2.34	2.80	3.12	0.03	0.00	0.00	0.00	0.00	0.02	0.01
	03.10.2001	5.1#	0.71	0.38	3.31	4.27	3.88	9.47	0.37	0.00	0.00	0.00	0.00	0.02	0.34

Fig.9 Synthetic assessment of track condition generated by GeoTEC database

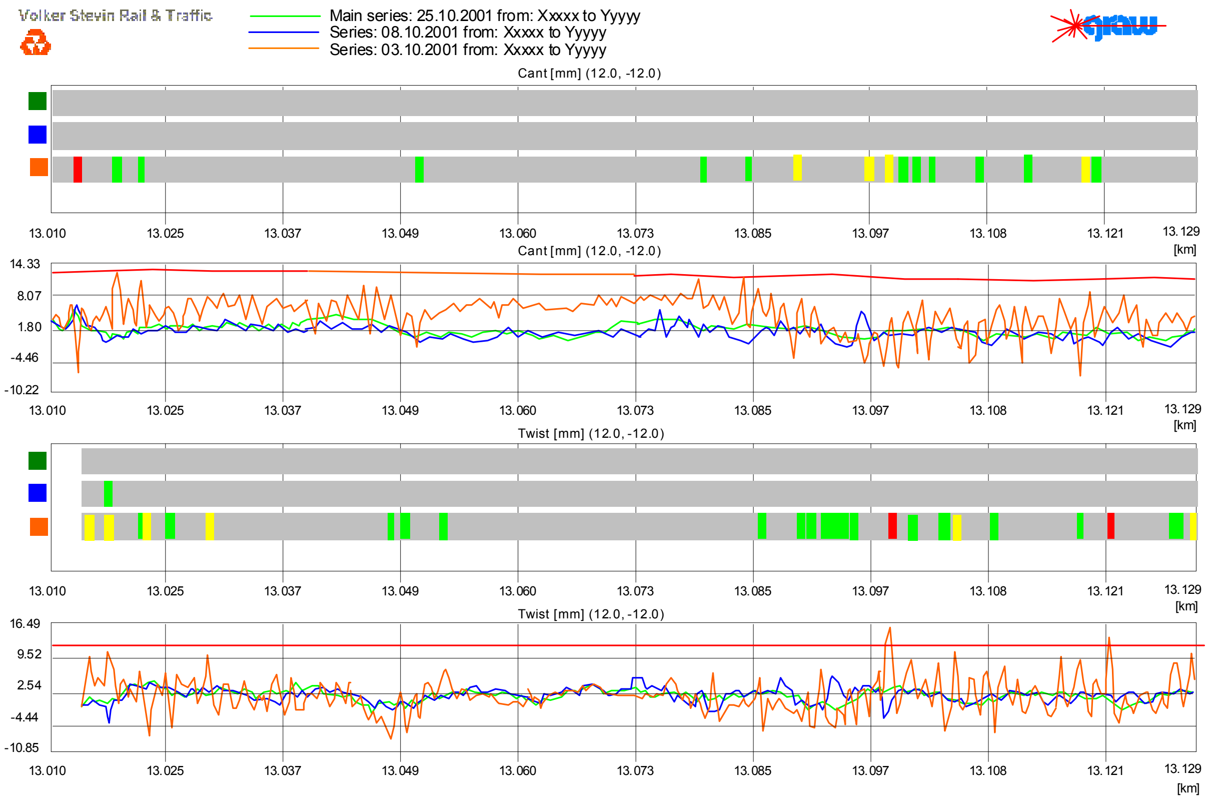

Fig 10 Track geometry before and after tamping, and futher after stabilizing

4.2 Stationary geometry car readings database

All measurements made by PKP geometry cars in Poland are stored in the database [11]. All this data features the basis for track improvement plan development by Infrastructure Management. The stationary data processing system is used for re-playing the geometry car readings to evaluate the effect of line speed limit on the line quality evaluation, and for analyses of the track condition changes in time.

As in the case of the GeoTEC database there is a model of the railway network in the background, featuring a reference framework for all readings. The system users can specify queries pertaining specific tracks, Districts, or quality of the entire lines from the entire railway network, with the averaged values for the entire network (fig.11). Therefore, the track quality synthetic coefficients feature the powerful tool for forecasting long term track quality changes, effects of the repairs done, influence of the local conditions, and evaluate the economical justification of the particular track maintenance strategies.

An important feature of this database is that the presentation tools operate on tables with the synthetic coefficients only. No information whatsoever on the track geometry details are needed at this level. The “bird’s eye” view of the railway network makes it possible to concentrate on the general trends, no matter from what measurements come the data. The integrated approach will make it possible to use the geometry car readings along with the data collected by track gauges.

Network track quality assessment report

Line ID	Track	Category.	Length [km]	Evaluated [km]	length of tracks satisfatory	unsatisfactory W5 > 0.6	J O.K.	J exceeded
D	1	0	222,028	55,206	55,014	0,192	10,149	45,057
D	2	0	222,028	1,264	1,264	0,000	0,121	1,143
1B1	1	0	491,948	272,703	234,446	38,257	262,184	10,519
1G1	2	0	491,948	97,130	76,130	21,000	96,130	1,000
A33	1	0	72,023	40,800	29,800	11,000	39,800	1,000
A33	2	0	72,023	45,998	34,499	11,499	45,198	0,800
G34	1	0	1 1,937	12,21 1	8,21 1	4,000	1 1,21 1	1,000
1H4	2	0	11,937	24,420	12,420	12,000	23,998	0,422
13C	2	0	10,477	10,875	7,875	3;000	8,000	2,875
1W8	2	1	22,220	22,999	20,000	2,999	21,000	1,999
74H	1	1	7,080	7,614	7,614	0,000	7,614	0,000
74H	2	1	7,080	10,098	9,098	1,000	9,698	0,400
Total for network			***1642,729***	***601,318***	**496,371**	***104,947***	***535,103***	***66,215***
Break up to								
Trunk lines		**cat. 0**		**560,607**	**459,659**	**100,948**	**496,791**	**63,816**
First-class lines		cat. 1		40,711	36,712	3,999	38,312	2,399
Second-class lines		cat. 2		0,000	0,000	0,000	0,000	0,000
Local lines		cat. 3		0,000	0,000	0,000	0,000	0,000

5. Conclusions

Many years long experience has revealed that the so called direct measurements made at particular points, carried out mostly by maintenance staff and documented in all logs and cards, play a limited role in taking decisions connected with main repairs. What they provide, is information necessary to decide about the immediate repairs of minor defects, and very often they are made only to observe the pertinent rules and instructions specifying rigorously terms and frequency of basic measurements, visual inspection and overhauls.

Current practice indicates that only the information provided by geometry cars and track gauges in the form of plots of particular track parameters and its synthetic coefficients, supplemented with the engineering analysis of the track history and regular visual inspection, feature a basis for taking the sound decisions regarding the type and scope of the track repair at the particular location.

Nevertheless, the experience shows that using pure statistics of defects in various classes, instead of making use of the real track data, like exact location of defects, local conditions, substructure type, etc, does not allow the infrastructure maintenance services to evaluate fully the track condition. One more deficiency of this statistics is that it separates different types of defects: twist from cant or vertical irregularities, or track gauge from its horizontal irregularities. The track, however should be perceived as an entity with its design data and geometry linked together. More to that, horizontal irregularities should be taken into consideration along with the condition of the track superstructure, and the horizontal irregularities with the stress values in rails. The problem is even more important as many hundreds or thousands of kilometers of track have to be analyzed on the District level. Synthetic track condition coefficient merges, in fact, the information about the geometrical quality of track with its other attributes, like rail condition, rail joints, rail fixing, ballast, sleepers, and dewatering. Let’s consider twist detected in some location – it may have a number of different causes, which have to be inspected on site during visual inspection:

Table 5 Exemplary twist cause and effect analysis

Defect	Possible cause
twist	◦ instability of the embankment ◦ weak substructure and littered ballast ◦ wrong shape of ballast prism ◦ poor condition of sleepers ◦ indentation of sole plates ◦ bad weld or butt joint ◦ … more to that, several of the above causes may occur, of course, simultaneously in a particular location

Therefore, the defect found is reflected by the synthetic coefficient of the track condition J. More than a decade of hands on experience [6] proves that this information, when used together with the knowledge of the track design (permanent way and substructure) and its historical values of this coefficient with the history of track maintenance, may help to specify the type and scope of the repair:

Analysis of the track condition should be carried out using the averaged J coefficient – this averaging is allowed for the uniform track sections in the design and historical respect. All locations in which the J coefficient differs significantly from other parts of the track should be analyzed individually.

1. To evaluate the track geometry condition one has to know not only the basic parameters measured with the manual devices, like track gauge and cant, but also other geometrical parameters deciding the dynamical effects of the train ride, i.e., track gauge gradient, track twist, as well as horizontal and vertical irregularities. This information may be obtained using the microprocessor based track gauges and geometry cars.
2. Detailed analysis of track geometry parameters’ plots assists taking the right decisions pertaining making urgent local repairs, i.e., to ensure safety of train operation. The knowledge of the synthetic track quality coefficients is required to take the economically justified decisions connected with planning of major overhauls of the longer track

sections. These decisions call for analysis of the track geometry changes in time. This analysis may be carried out by the dedicated software for management and analysis of the track measurement results acquired for track gauges and geometry cars.

3. Positive experiences gathered in operation of the microprocessor based track gauges and with track geometry quality assessment basing on analysis of parameter plots and synthetic coefficients give ground to work out similar methods, based on continuous switch geometry measurements, for evaluation of switch condition. This novel attitude will effectively supplement the switch geometry assessment made basing on measurements in characteristic points only to date.

Bibliography

1. Henryk Bałuch, ”Diagnostics of track structure”, WKiŁ, Warsaw, 1978, (in Polish)
2. Henryk Bałuch, “Quality Management of track repairs”, Problemy Kolejnictwa, Fascicle 130, Warsaw, 1999, pp. 5-24 (in Polish)
3. Bożysław Bogdaniuk, „Maintenance of tracks using the integrated diagnostics system”, Proceedings of the First Seminar on Diagnostics of Permanent Way, Gdańsk 18-20 May, 1999, Poland, pp.41-66 (in Polish)
4. Jacek Burghardt, Maciej Iwaszkiewicz, Janusz Madejski, “System for the real time railway track geometry parameters evaluation”, Proceedings of the 7th International Conference on Signal Processing Applications & Technology, Boston, Massachusetts, USA, October 7-10, 1996, vol. 2, pp.1821-1825
5. Franz Eglseer: "Recording Track and Catenary Geometry at 250 km/h", Railway Gazette International, August 1995, pp. 507-509
6. Leszek Lewiński, Dariusz Szczepiński, “Planning of track maintenance based on the synthetic coefficient value analysis”, Proceedings of the Second Seminar on Diagnostics of Tracks, Gdańsk 24-26 May, 2000, Poland, pp.75-88 (in Polish)
7. Janusz Madejski, Juliusz Grabczyk, “Track and Rolling Stock Quality Assurance Related Tools”, Proceedings of the International Conference on Computer Aided Design, Manufacture and Operation in the Railway and other Advanced Mass Transit Systems - COMPRAIL 98, Special Session on Safety of High Speed Trains, 2-4 September 1998, Lisbon, Portugal, published later as a chapter in a book: “Structural Integrity and Passenger Safety” - Wessex Institute of Technology, 1999, pp.85-114
8. Bulletin of the Polish State Railways, Annex to the Order No. 86 of the Polish State Railways (PKP) Headquarters of 14 November 1996: D 75 – Instruction on Taking Measurements, Examinations and Assessment of Track Condition
9. User Manual for TEC-1435 Track Gauge, GRAW, 1999 (in Polish)
10. User Manual for EM-120 Geometry Car, GRAW, 1997 (in Polish)
11. User Manual for Stationary Track Diagnostics System, GRAW, 1999 (in Polish)