



VALIDATION OF PAVEMENT CONDITION EVALUATION BY USING MOBILE MAPPING SYSTEM

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Abstract

Road operators need to measure pavement condition from time to time to plan the renovation and maintenance strategy. Two key pavement indicators are the International Roughness Index (IRI) and rutting depth. In Hungary, Road Surface Tester (RST) is being used for pavement assessment. As the land survey technology improves, high frequency data collecting and processing becomes more available for everyday engineering practice. Beside traditional land survey usage of mobile mapping systems (MMS), pavement condition evaluation becomes possible to obtain. For proving this concept, pilot project was organized, involving three manufacturers, four road sections with a combined length of 11.5 km, from very good quality (IRI < 1.00 mm/km) to poor quality (IRI > 5.00 mm/m). Repeatability and consistency was tested, while the bias proved the validity of the model. The results of the pilot project showed that pavement assessment is possible by using mobile mapping system and the right evaluation software.

Keywords: pavement evaluation, mobile mapping system, IRI, rutting depth

1 Introduction

Road operators are obliged to evaluate pavement condition in Hungary. Pavement condition includes longitudinal and cross-sectional unevenness, surface friction, texture, bearing capacity, cracking and other visual assessments. Therefore multiple devices are in use: road surface tester (RST), airport surface friction tester (ASFT), sideways-force coefficient routine investigation machine (scrim), falling weight deflectometers (FWDs), curviometer, roadmaster-2000 etc. The most important indicators are International Roughness Index (IRI, mm/m) and rutting depth (mm) as they are directly attached to riding quality and road safety. The above mentioned measurements can barely keep the traffic speed, causing significant safety concerns. The development of data collecting and processing reveals the opportunity for land survey devices as mapping systems to be introduced in condition assessment and construction quality control. A road operator is also a designated asset manager, who wants to gather as much data of the operated assets as possible. These considerations triggered a bigger pilot project where mobile mapping systems were tested to evaluate IRI and rutting depth. Three major manufacturer took part and a standard RST to serve reference results. In the last decade there are some mentionable papers and test that dealt with similar problems [1, 2].

2 Pilot project

2.1 Location

IRI was the principal indicator in the selection process, quality of the road sections covered the whole measurement range. All four sections were located in North-Western Hungary, one motorway section and three local roads. The quality of local roads differed from good to poor.

- M85 1+000 – 11+000 km right side, lane 2
- No. 8417 – 8+400 – 8+900 km, left side ($IRI < 2$; “good”)
- No. 8314 – 53+500 – 54+000 km, right side ($5 > IRI > 2$; “moderate”)
- No. 8419 – 0+500 – 1+000 km, right side ($IRI > 5$ mm/m; “poor”).

The measurements were carried out at three different speeds:

- motorway: 60 – 90 – 105 km/h
- local roads: 30 – 60 – 90 km/h.

Three repetitions were made at each speed to test the repeatability. Base point system for point cloud fitting was built up on each test section with 50 m distances between base points to reach absolute precision.

The pilot project was implemented in April 2025.

2.2 Measurement tools

2.2.1 Road surface tester

The reference car was the road surface tester commonly used for pavement condition evaluation. A car has a cross-beam at the front with 15 – 19 high frequency laser sensors depending on lane width facing downward to measure vertical distances [3]. IRI, rut depth according to different evaluation techniques, cross-slope, surface wave length and surface texture can be measured. The measuring speed is 80 km/h. The RST detects the surface on 15-19 points therefore a curve must be fitted on them to create the virtual surface profil. Calculations are based on the fitted curve.

2.2.2 Mobile mapping systems

Three major manufacturers took part in the project with their best-available technology. Table 1 summarizes the main characteristics of the devices [4-6].

Table 1 MMS characteristics

Parameters	Leica TRK700 Evo	Riegl VUX-1HA ²²	Trimble MX90
Absolute accuracy in [X,Y], [Z]	14 mm, 16 mm	5 mm	5 mm
Precision	1 mm	3 mm	3 mm
Maximum pulse rate	2 x 2.2 MHz	1.8 MHz	1.8 MHz
Maximum range at 10% reflection	182 m	85 m	85 m
Field of view	360°	360°	360°
Software	TopoDOT	Atlas	Trimble Business Center

Point clouds were collected by mobile mapping systems with high density and were fitted to base point system. Different softwares were used for evaluation and calculation of the examined indicators.

2.3 Indicators

2.3.1 International roughness index

International Roughness Index was introduced by the World Bank in 1986 [7]. The calculation of longitudinal unevenness is based on a fictional, standardized quarter car (Golden Car Model). Vertical displacement of sprung mass is measured and corrected with acceleration of sprung and unsprung masses. Detailed calculation with filtering techniques were published [8, 9]. IRI is a good indicator of riding comfort and is in direct connect with CO₂ emission of vehicles while its correlation with bearing capacity is also high.

2.3.2 Rutting depth

Rutting depth is the permanent deformation of pavement in cross-sectional direction. It means the vertical deterioration of pavement surface in the wheelpath. Two standardized method is known to measure rutting depth [10]:

- “Beam method”
- “Wire method”

The difference between the two principles is measuring vertical displacement under a rigid beam that can “sit” at the two highest points of cross section or under a wire that can be stretched on the three highest points of cross section. Although the RST measure and calculate both, the “Wire method” is used as quality indicator in general so it was in the pilot project meaning that the maximum of the left and right rutting depth was calculated separately.

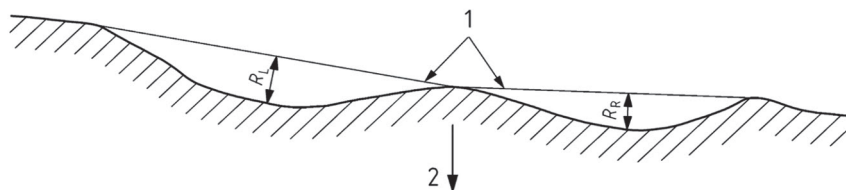


Figure 1 Rutting depth measurement [10]

2.4 Tests and analysis

2.4.1 Repeatability

Hungarian Road Technical Specifications [11] determine repeatability requirements for RST measurements. The same methods were used for MMS results. Let x be the average of two measurements on the same section and y their difference:

$$x = (x_1 + x_2) / 2 \quad (1)$$

$$y = |x_1 - x_2| \quad (2)$$

IRI:

$$\text{if } x \leq 2 \text{ mm/m, then } y \leq 0.5 \text{ mm/m or if } 2 < x \leq 4 \text{ mm/m, then } y \leq 1 \text{ mm/m} \quad (3)$$

Rutting:

$$\text{if } x \leq 5 \text{ mm, then } y \leq 1 \text{ mm or } 5 < x \leq 20 \text{ mm, then } y \leq 1 + 0.2(x - 5) \text{ mm} \quad (4)$$

A measurement is repeatable if 80% of the point-pairs fulfill the above mentioned requirements. Hungarian Road Specification [11] chose a 100 m base length for evaluation, but 20 m was chosen for stricter requirements in pilot project.

2.4.2 Analysis

For analyze the results, linear regression was calculated:

$$RST = m \cdot MMS \quad (5)$$

$$m = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2} \quad (6)$$

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2} \quad (7)$$

Errors and bias were also analyzed:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (8)$$

$$MAE = \frac{1}{n} * \sum_{i=1}^n |y_i - \hat{y}_i| \quad (9)$$

The difference between RMSE and MAE is that RMSE gives more weight to bigger errors due to quadratic formula. Bias were analyzed with distribution functions.

3 Results and discussion

Results have shown that Leica & TopoDOT performed the best evaluation. Due to length restrictions, the figures in this paper contains the results of Leica and RST.

3.1 Repeatability

Equations (1) – (4) were used for both IRI and rutting depth. All IRI repeatability test was successful. Every device produced results between 89.0 – 99.5% on 20 m base length. Leica and RST was above 98%. The distribution differs a bit, as the MMS can produce almost the same result even in higher ranges.

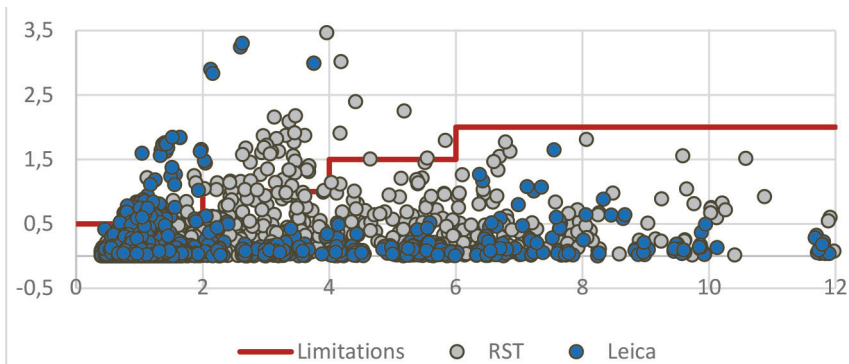


Figure 2 IRI repeatability test

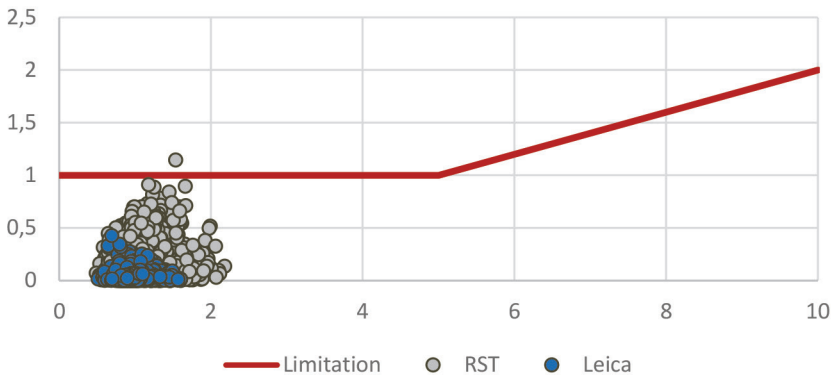


Figure 3 Rutting depth repeatability test

Rutting depth repeat test was conducted only for Leica and RST. Only one single data pair of RST exceeded the limitations, while none of the MMS points. The differences on figure 3 is remarkable, but reasonable. The RST has bigger noise due to cross-sectional movement and MMS point cloud is not depend on what wheelpath the car took.

3.2 IRI results

Equations 5–9 were calculated. Trimble could not produce enough results to be comparable, therefore only Leica and Riegl results are summarized in table 2. The results showed that Leica IRI calculation with TopoDOT was identical with the reference results, while Riegl had also a good correlation.

Table 2 IRI results

Results	Leica	Riegl
m	0.98	0.79
R ²	0.96	0.81
RMSE	0.37	0.90
MAE	0.14	0.69

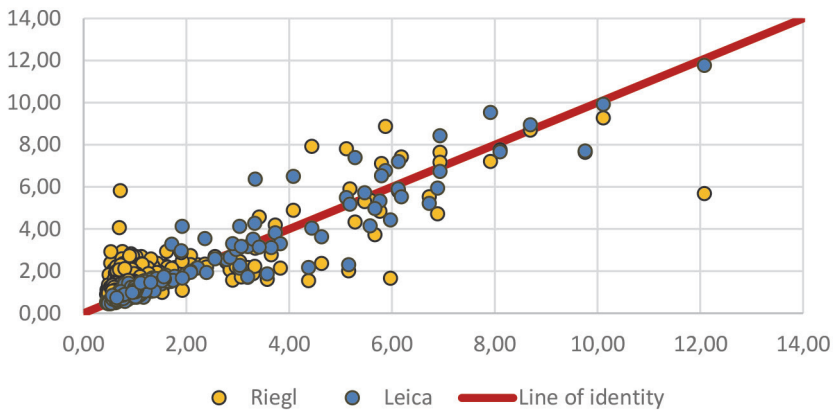


Figure 4 RST and MMS comparison for IRI

Bias were analyzed to identify whether there is any trend in errors, table 3. The results showed that bias of Leica are distributed symmetrically in a narrow range around zero, meaning they are random, while Riegl has a trend that can be corrected, figure 5.

Table 3 IRI bias

	Leica	Riegl
Expected value	0.00	0.52
Median	-0.002	0.51
Range	5.88	11.50
Sum	0.14	299.16

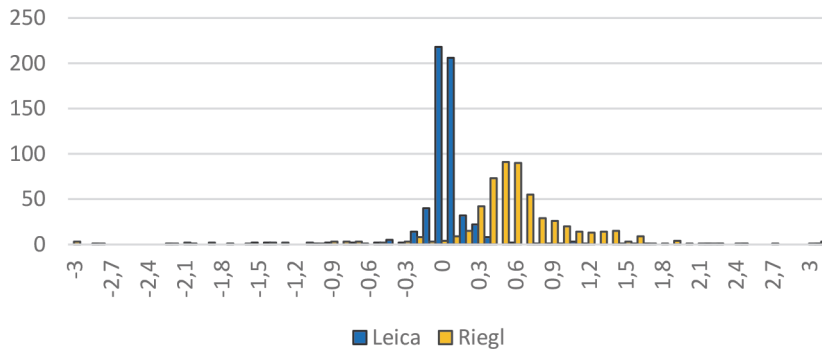


Figure 5 Distribution of IRI bias

3.3 Rutting depth results

Rutting depth was analyzed only for Leica results. Same calculations were carried out and the results are similar to IRI although errors are a bit bigger, figure 6 and table 4.

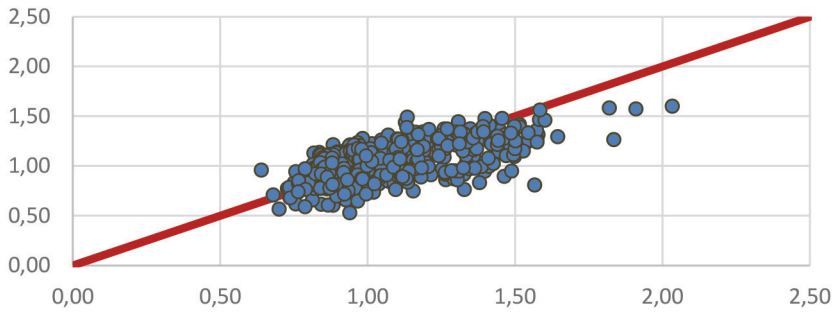


Figure 6 RST and MMS comparison for rutting

Table 4 Rutting results and bias

	Leica
m	1.02
R ²	0.97
RMSE	0.18
MAE	0.13
Expected value (bias)	-0.03
Median	-0.008
Range	1.11
Sum	-14.86

3.4 Effect of speed

Different travel speed were tested to analyse whether the density of point cloud has any effect on results. Data showed that goodness of fit is independent of travel speed.

4 Conclusion

Mobile mapping systems were tested at different travel speed and pavement quality to find out whether they are capable of evaluate pavement quality indicators served by Road Surface Tester. Four different test sections were involved covering all the measurement range. The tested indicators were IRI and rutting depth. Leica MMS with the evaluation software TopoDOT could deliver the same identical results as the reference car with R² of 0.96 and 0.97. Bias were analyzed and normal distribution was found, meaning they are random. Riegl could produce reasonable results but correction has to be made to reach the same conclusions. Mobile Mapping Systems are powerful tools for road operator. Further research areas need to be tested as construction quality control or asset management.

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