

# **ROAD ROUGHNESS MEASURED BY PROFILOGRAPH IN RELATION TO USERS'S PERCEPTION AND THE NEED FOR REPAIR: A CASE STUDY**

**BY**

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## Abstract

In the present case study, profile measurements using the Danish Road Institute (DRI) laser profilograph were performed on a semi-rigid pavement of the primary Greek motorway network. The major damage was the roughness in early stage of service life. On the purpose of providing information for more acceptable decisions on the need for pavement repair, a panel experiment was also conducted by the Department of Transportation Planning and Engineering of National Technical University of Athens (NTUA). The present paper includes the field data analysis that comprises several aspects concerning possible variability of the obtained International Roughness Index (IRI) based on the measured profile path. Furthermore the development of simplified transformation functions that link the ride quality and the pavement roughness with the need for repair is included. The latter ones are used towards the target of establishing acceptable IRI trigger levels of need for repair. The results of this case study indicate that the selection of the way of the IRI reporting for the evaluation of the pavement roughness might be quite important when non-routine maintenance issues related to allocation of funds are considered.

## INTRODUCTION

One of the primary factors that affect road serviceability is the pavement surface quality. This is usually expressed in terms of roughness, which is related to the users' opinion of the level of service provided by a pavement surface. This is mainly affected by the pavement profile that may be measured in the field by using a variety of devices. It may be also estimated by taking into account the vehicle wheels movements and suspension system together with the users' sensitivity to speed and acceleration.

Highway engineers prefer to evaluate the pavement surface quality by measuring physical properties, such as roughness, that may be determined objectively. However, despite the rapid technological improvement of high speed roughness monitoring equipment, it should not be overlooked that roadway pavements are built for the users, who have ever been keenly aware of the relative degrees of comfort or discomfort experienced by travelling (*1*). Therefore their perception on road surface quality should be also taken into account.

The present work concerns the serviceability level related to one of the main Greek Motorways. The semi-rigid pavement of the present study was under traffic only for about three years. Nevertheless, road users were complaining about the pavement rideability. Roughness was undoubtedly the primary damage and in that case the need for repair of the pavement roughness condition was more than essential. Although the international literature in the subject refers more to end-results specifications concerning the acceptance of new constructed asphalt pavements, it seems that there is not enough information for direct applicability when non-routine maintenance matters for rather early stage pavement roughness related damages are concerned (*2, 3, 4*).

The motorway under investigation was initially constructed by several contractors i.e. it was divided into subsections assigned to each contractor. So there was an urgent need to establish a rather simple methodology able to identify thresholds and trigger levels of the need for roughness repair in every subsection. For this reason the Department of Transportation Planning and Engineering of National Technical University of Athens (NTUA) was involved in the case study as an independent authority. NTUA in co-operation with the Danish Road Institute (DRI) evaluated the pavement roughness as a part of a pilot study financed by the 2<sup>nd</sup> European Union Cohesion Fund on the purpose of the Trans-European Network (TEN). Furthermore, in order to achieve the most appropriate way of evaluating the pavement roughness in terms of the road users' perception NTUA conducted a combined field experiment comprising roughness measurements and panel ratings.

The proposed procedure was based on the users' perception of the riding quality. The main goal was to establish acceptable from both, the Agency Service and the contractors, trigger levels for repair so that the involved parts could have a useful tool as a preliminary basis for better allocation of maintenance funds. The experience obtained from the aforementioned case study and the related findings are presented and discussed in this paper.

## PANEL EXPERIMENT

### Design of the Panel Experiment

The design of the present panel experiment was consistent with those of other similar studies (among others Paterson (5), Potter (6)). These studies investigated among others the rating method, the panel formation and the selection of the test road sections. Eighteen motorway subsections were selected as pavement test sections for the field experiment at straight and level topography. It is noted that the length of each test section was 200 meters.

The panel group, which covered an appropriate mix of vehicle users in terms of sex, age and driving experience, consisted of 17 raters (among others Nakamura and Michael (7), Nick and Janoff (8)). The composition and the size of the panel group were also acceptable according to the context of the International Road Roughness Experiment (IRRE) (Sayers et al.(9), Loizos et al, (10)).

Considering the selection of the survey vehicle, the majority of researchers claim that the vehicle type does not have a significant influence on the panel rating and therefore rating exercises were often limited to K-cars (8). However other studies have shown (among others Loizos, et. al. (10) and Sayers and Karamihas (11)) that the vehicle type should not be ignored, as wavelengths affect each type of vehicle in a different way. Furthermore, according to McLean and Ramsay (12), truck drivers may be more sensitive than car occupants to long wavelength roughness that induces pitch and roll response modes, and also to roughness, affecting vibratory comfort.

To sum up and to avoid any confusion, one approach could be to request the rater to assess the acceptability of the vehicle, as reported in some research studies in the area of vehicle dynamics (13). In the context of the present experiment, it was decided to overcome the problem by asking the raters about the "pavement ride quality" as opposed to asking them to evaluate the "ride". When posing the first question one should rate the quality of the pavement surface irrespectively of the vehicle type, whereas when posing the question of "how is the ride", the information sought from the raters is dependent on the vehicle type. However in the present research the traffic composition of the road sections under investigation indicated that a simplified approach, that of considering one vehicle type, would not affect significantly the accuracy of the analysis. Consequently, a medium sized vehicle that was considered representative of the average vehicle fleet in Greece was selected for the present survey.

As far as the survey speed is concerned, it was selected to be approximately 80 Km/h. This is considered as a typical speed for undertaking panel experiments for the subjective evaluation of pavement roughness (10, 14). During all panel experiments, the speed remained constant and relatively low. However, it should be noted that the user is likely to differentiate his/her opinion on the ride quality of the pavement, depending on the high or low vehicle speed.

### Conduct of the Experiment

It is well known that there are forms of distress and severity levels, which influence the pavement roughness significantly, but there are also distress forms, which especially at low levels of severity do not have an important effect on the longitudinal profile. For the latter types of distress, to wait until the roughness reaches a trigger level for maintenance would be to wait too long plus the time when the distress could be cost-effectively repaired. At this point a complete and costly reconstruction may be required. In this case the subjective evaluation of pavement roughness should be considered as a more effective tool for the assessment of the maintenance need.

It is estimated that the most effective way to determine trigger roughness values, where non-routine maintenance interventions are needed, is to consider the users response as far as rideability is concerned. One suitable method for setting roughness trigger values for rehabilitation is to determine the level at which at least 50 percent of highway users decide that the pavement ride is unacceptable for a given functional class and pavement type (15).

During the present panel experiment the raters were asked about whether there is a need for repair of the investigated road pavement sections or not. Following this procedure, the set of yes or no answers was

used to derive percentages of the need for maintenance for each road pavement section. The percentages were expressed through the indicator NR (Need for Repair), which is used for the acceptability or not of the pavement surface quality.

In addition the raters were asked to obtain the Panel Rating value of each road section following the related procedure established during the International Road Roughness Experiment (IRRE). Specifically, the raters were asked to rate the pavement ride quality on a numerical scale ranging from zero to five, (5), where 0 indicates an extremely rough pavement (unacceptable) and 5 corresponds to the roughness of a new pavement (see figure 1). Based on the panel rating data obtained, the Mean Panel Rating (MPR) was determined for each test section.

## PROFILE MEASUREMENTS

Since road roughness profiling became a feasible technology for highway agencies, research establishing a link between profile properties and rideability is necessary so that roads may be maintained or constructed to meet the requests of both engineers and users. Of course, there is still lack of roughness harmonization in data obtained using different measuring approaches. However the International EVEN Roughness Experiment (16) conducted by the Committee C1 of PIARC (17) will probably contribute significantly towards this goal.

For the project under discussion, the profile measurements were carried out using the multi-laser profilograph of the DRI (18). This profilograph consisted of 25 lasers located on a beam in the front of a car. For each laser, measured data was stored singly keeping also the capability of changes and remarks. The data procession provided the profile of the pavement surface focusing mainly on the estimation of the International Roughness Index (IRI).

It is noticed that although the IRI is defined as a property of a single wheel profile, there are no internationally harmonized guidelines regarding where the profiles should be located and how many of them should be used. The IRI summarizes the roughness qualities that impact vehicle response and is felt appropriate when a roughness measurement is desired that relates the overall ride quality to the pavement surface condition. However, the general experience showed that the profiles should be recorded along the two wheel paths, with the IRI values for each being averaged to obtain a summary IRI for the traffic lane (19). According to Rogers et al. (20) in most cases, the right or the outside wheel path was found to be predominant rougher. However the differences between the wheel paths were not statistically significant in a study undertaken by Hajek (21). Besides (Gillespie, 1992) has shown that the IRI value from a car-based system is inherently 10% to 20% lower than the average of the IRI values of the two wheel tracks.

In the present study the IRI values were obtained by taking into account three specific lasers, the two ones corresponding to the left and right wheel paths respectively and the third one corresponding to the in-between path. It is mentioned that the latter one was taken into account since it can provide also additional information about the transverse unevenness and more specific to identify possible black spots for rutting damages.

## DATA ANALYSIS

### Correlation of Objective Roughness Measures

For each test section, 3 sets of IRI values were calculated based on: (a) the average of the IRI values computed for the left, the right and the in-between path profile, denoted as  $IRI_3$ , (b) the average of the IRI values computed for the left and right wheel-track profiles, denoted as  $IRI_2$  (c) the IRI values obtained from the right wheel path, denoted as  $IRI_{rwp}$ . The first task was the investigation of the relation between the three indices i.e.  $IRI_3$ ,  $IRI_2$  and  $IRI_{rwp}$ .

According to the results of the applied regression analysis (see table1), the best fit is achieved for the correlation between  $IRI_3$  and  $IRI_2$ . The correlation is proved to be good and in the three aforementioned cases.

### Panel Ratings Versus Profile Measurements

As far as the subjective measures of roughness are concerned, the subjective panel ratings MPR were correlated with each objective measure of roughness  $IRI_3$ ,  $IRI_2$  and  $IRI_{rwp}$  using regression analysis. The question about which of the three transforms can be used to predict the users' perception of pavement rideability more accurately was addressed.

Table 2 summarizes the results of the analysis for the surface types investigated for three different forms of regression: linear, polynomial and exponential. It also shows the corresponding  $R^2$  coefficients for each of the transforms. It is noted that the values obtained are relative low, but since there is an amount of ambiguity and vagueness concerning the subjective measures of the public's perception of existing pavement rideability, these values could be considered as quite satisfactory.

The  $R^2$  values showed a close agreement between MPR and  $IRI_{rwp}$ . This fact leads to the conclusion that the raters are more sensitive to the right wheel path profile. This finding is reinforced from the fact that the  $R^2$  coefficient is even lower for the correlation between MPR and the  $IRI_3$  index.

The above transforms established between subjective panel ratings and physical longitudinal profiles provide an alternative method for roughness evaluation and provide a simplified approach for the conversion of MPR to IRI values. This approach becomes even simpler when using linear forms of regression as in table 2 (see also figure 2).

It is worthwhile to mention that the above models, developed to predict MPR, are suitable for the range of the analyzed field data considered. This indicates that a greater data range could be the subject for future investigation, taking into account that there are quite a few forms of regression, which could be used in view of pavement roughness assessment based on subjective and objective measures (23).

### Assignment of Pavement Non-Routine Maintenance Trigger Levels

The previous data analysis resulted in the development of transform equations between IRI and MPR values. However the potential problem of assigning a trigger value for resurfacing and reconstruction works is still outstanding. Both the road users perception of rideability and the structural integrity of the pavement must be considered.

The NR values thus the percentages of the driving public that believes a given surface requires repair were computed. The objective of the subsequent analysis was to determine the relationship between MPR and NR. A linear form of regression was applied and the following transform was obtained based on the panel experiment data (see figure 3).

$$MPR = -0.009 NR + 4,021 \quad (1)$$

The good correlation coefficient ( $R^2 = 0.78$ ) seems to indicate that the travelling public is quite clear with regard to their expectations of the ride quality for the various road test sections. So based on the aforementioned transformation equation (1) for  $NR=50\%$  the MPR value is approximately equal to 3.57.

Al-Omari and Darter (24) have also developed similar equations correlating the Present Serviceability Rating (PSR) with the NR, as also with IRI. Substituting the equation that linked PSR and IRI in the equation that linked PSR and NR, a transform equation was obtained that related IRI with NR.

Besides, in the present study, a direct relationship between the need for repair NR and IRI was developed to facilitate the decision making on the need for non-routine pavement maintenance when using only profile measurements, i.e. avoiding the need of an extensive subjective pavement ride quality evaluation. So a simple linear regression analysis was applied in order to correlate NR with  $IRI_3$ ,  $IRI_2$  and  $IRI_{rwp}$  respectively. The target of this regression analysis is the estimation of IRI based on the acceptability percentage of the raters regarding roughness. The admission is that the independent value is NR and the dependent one is IRI (see figure 4). In the table 3 the results of that regression analysis are shown.

The correlation coefficient, when the NR versus IRIs, are more or less quite satisfactory whereas the analysis was based on a rather limited data set. Using the above equations for the estimation of the IRI

for NR=50% we get the results of column A table 4. The same procedure could be followed using the linear regression, which correlates MPR and IRI. So for MPR=3.57 (NR=50%) and following the regression analysis of figure 4 we get the results of the column B of table 4.

The results of the two aforementioned cases are too close (Table 4). So it could be considered that the obtained trigger values for non-routine maintenance are 1.86, 1.88 and 1.96 versus IRI<sub>3</sub>, IRI<sub>2</sub> and IRI<sub>rwp</sub> approach respectively.

### APPLICATION OF THE TRIGGER VALUES

The next step was the application of the developed trigger values on the measured pavement roughness along the motorway under investigation considering the three approaches of IRI i.e. IRI<sub>3</sub>, IRI<sub>2</sub> and IRI<sub>rwp</sub> as individual cases. Figure 5 describes the percentages of the pavement surface, which present the need for repairing the roughness based on the assigned trigger values.

According to the results shown at figure 5, the need for roughness repair is presented for the 44% and the 46% of the pavement surface when the IRI<sub>3</sub> and the IRI<sub>2</sub> indicators are considered respectively, while in the case of IRI<sub>rwp</sub> the percentage in question goes up to 91%. These results led to some questions about the choice of the path, which should be considered, when the target of the profile measurements focuses towards non-routine maintenance of the pavement roughness.

### CONCLUDING REMARKS

The main results of the present case study highlighted a number of aspects and findings, which could be summarized in the following:

- The correlation between the IRI values obtained for the paths considered in this study (a. the right and left wheel path and the in between path profiles, b. the right and left wheel path profiles and c. the right wheel path profile) was found to be very good. The best fitting was achieved for IRI<sub>rwp</sub> and IRI<sub>2</sub>, a finding, which proves that the middle path profile doesn't affect the evaluation of the longitudinal pavement roughness. However, it should be mentioned that it provides a good indication of the transverse profile.
- The quite satisfactory value of correlation coefficient for the MPR and IRI values obtained by the right wheel path profile measurements, shows that the users perceive the road surface roughness through the on side vehicle wheel's vibrations. Further improvement of the statistical correlation based on a greater set of field data would be worthwhile. It is noted that the panel experiment could be repeated also using trucks in order to investigate whether the pavement ride quality is likely to be different in this case.
- The regression analysis of the MPR and NR indices convinces that the correlation coefficient is quite satisfactory ( $R^2=0.78$ ). A simple linear transformation was applied to indicate the MPR trigger value for roughness maintenance corresponding to the 50% of the raters who expressed the need of repair.
- The correlation coefficient for NR and IRI indices is not quite satisfactory. Nevertheless a relation between them, presented by a simple linear transformation, is obtained. This transformation is used in order trigger levels of IRI approaches i.e. IRI<sub>3</sub>, IRI<sub>2</sub> and IRI<sub>rwp</sub> to be developed.
- The combined analysis of the above two findings leads to the development of some IRI trigger values depended on the profile path selected for the evaluation of the longitudinal pavement roughness. For the case study the motorway IRI trigger values ranged from 1.86 to 1.96 m/Km when NR index is equal to 50%, in other words when the need for pavement repair is recognized as essential.
- When the IRI trigger values were applied to all measured profile data along the motorway, the quantification of the need for repair of the pavement surface was diversified. The big difference was pointed when the IRI<sub>rwp</sub> trigger value was obtained and the percentage of the pavement surface along the motorway caught up the 91%, while in the other cases, i.e the applied IRI<sub>3</sub> and IRI<sub>2</sub> trigger value, the percentage in question was 44% and 46% respectively. Based on the above outcome it is anticipated that the selection of the IRI approach would have also an impact when referring specifically to the subsections allocated to the several contractors.
- Consequently, the selection of the way of the IRI reporting for the evaluation of the pavement roughness might be quite important when pavement maintenance non-routine issues related to allocation of funds are considered. The latter could have also an impact when PMS related issues are concerned.

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**TABLE 1**      **Correlation of Obtained IRI Values**

<i>Correlated variables</i>	$R^2$
<b>IRI<sub>3</sub> - IRI<sub>2</sub></b>	0.97
<b>IRI<sub>2</sub> IRI<sub>rwp</sub></b>	0.94
<b>IRI<sub>3</sub> - IRI<sub>rwp</sub></b>	0.88

**TABLE 2** Results of Regression Analysis (MPR = f(IRI))

<i>Correlated variables</i>	<i>Regression forms</i>	<i>Transform equations</i>	<i>R<sup>2</sup></i>
<b>IRI<sub>3</sub>-MPR</b>	Linear	MPR = -0.317 IRI+4.187	0.56
	Polynomial	MPR = -0.16 IRI <sup>2</sup> +0.26IRI+3.72	0.59
	Exponential	MPR = 4.242e <sup>-0.09009 IRI</sup>	0.55
<b>IRI<sub>2</sub>- MPR</b>	Linear	MPR = -0.317 IRI+4.188	0.64
	Polynomial	MPR = -0.02 IRI <sup>2</sup> -0.24 IRI+4.12	0.65
	Exponential	MPR = 4.243e <sup>-0.09008 IRI</sup>	0.63
<b>IRI<sub>rwp</sub>-MPR</b>	Linear	MPR = -0.319 IRI+4.212	0.72
	Polynomial	MPR = -0.01 IRI <sup>2</sup> -0.29 IRI+4.19	0.73
	Exponential	MPR = 4.271e <sup>-0.090048 IRI</sup>	0.71

**TABLE 3**      **Linear Regression Analysis of NR with IRI approaches**

<i>Correlated variables</i>	<i>Transform equations</i>	$R^2$
<b>NR - IRI<sub>3</sub></b>	$IRI_3 = 0.0186 \text{ NR} + 0.93$	0.60
<b>NR - IRI<sub>2</sub></b>	$IRI_2 = 0.0213 \text{ NR} + 0.82$	0.68
<b>NR - IRI<sub>rwp</sub></b>	$IRI_{rwp} = 0.0226 \text{ NR} + 0.83$	0.69

**TABLE 4**      **Developed IRI Trigger Values**

	<i>Column A</i>	<i>Column B</i>
	<b>IRI = f (NR)</b>	<b>MPR = 3.57</b>
<b>IRI<sub>3</sub></b>	1.86	1.85
<b>IRI<sub>2</sub></b>	1.88	1.87
<b>IRI<sub>rwp</sub></b>	1.96	1.95

**Section:**  
**Name :**

5 **Best**

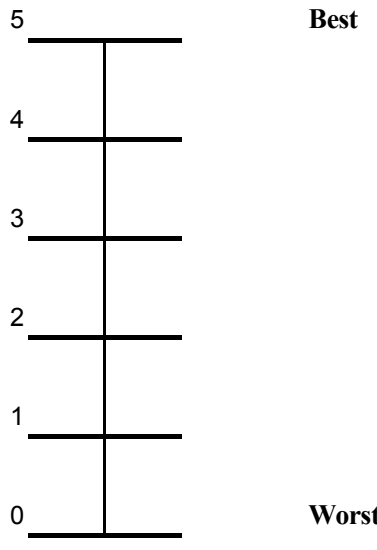
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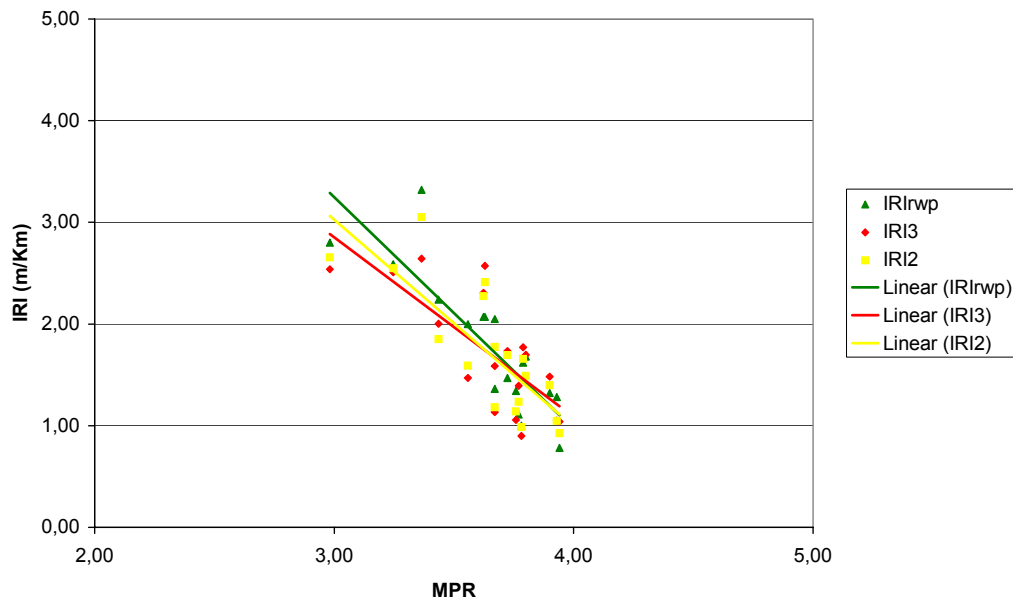
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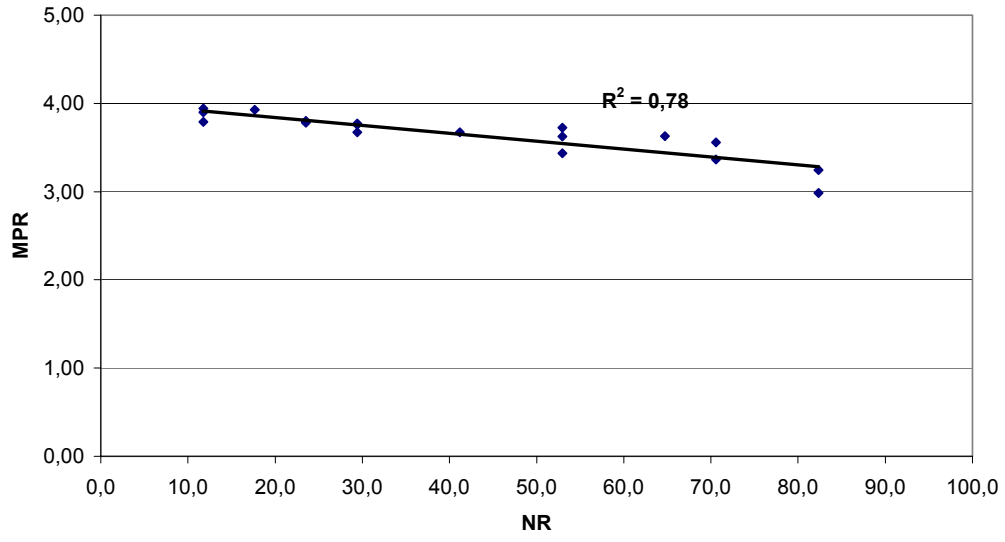
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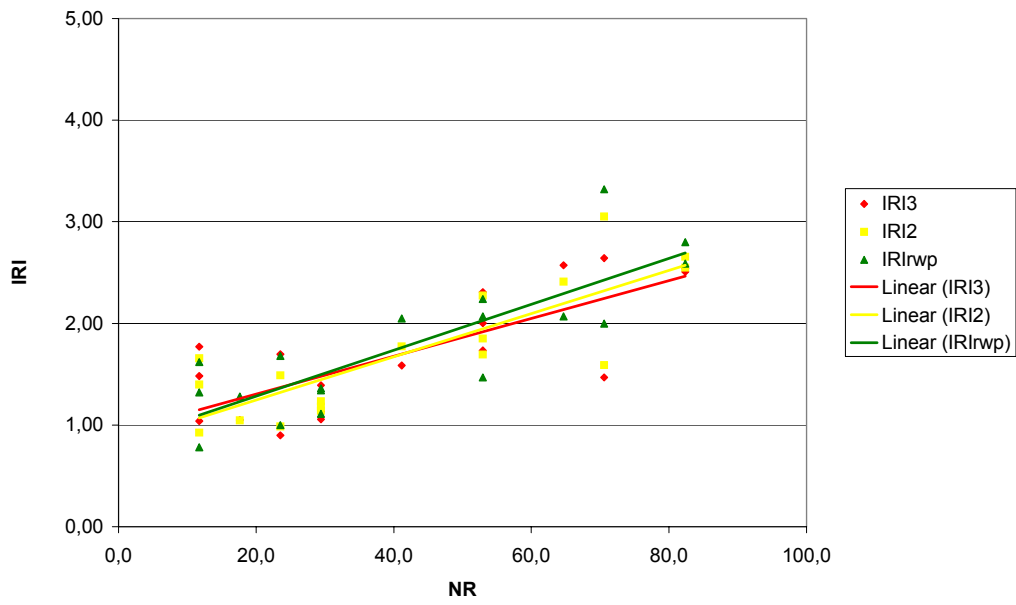
**FIGURE 1 Individual rating form**



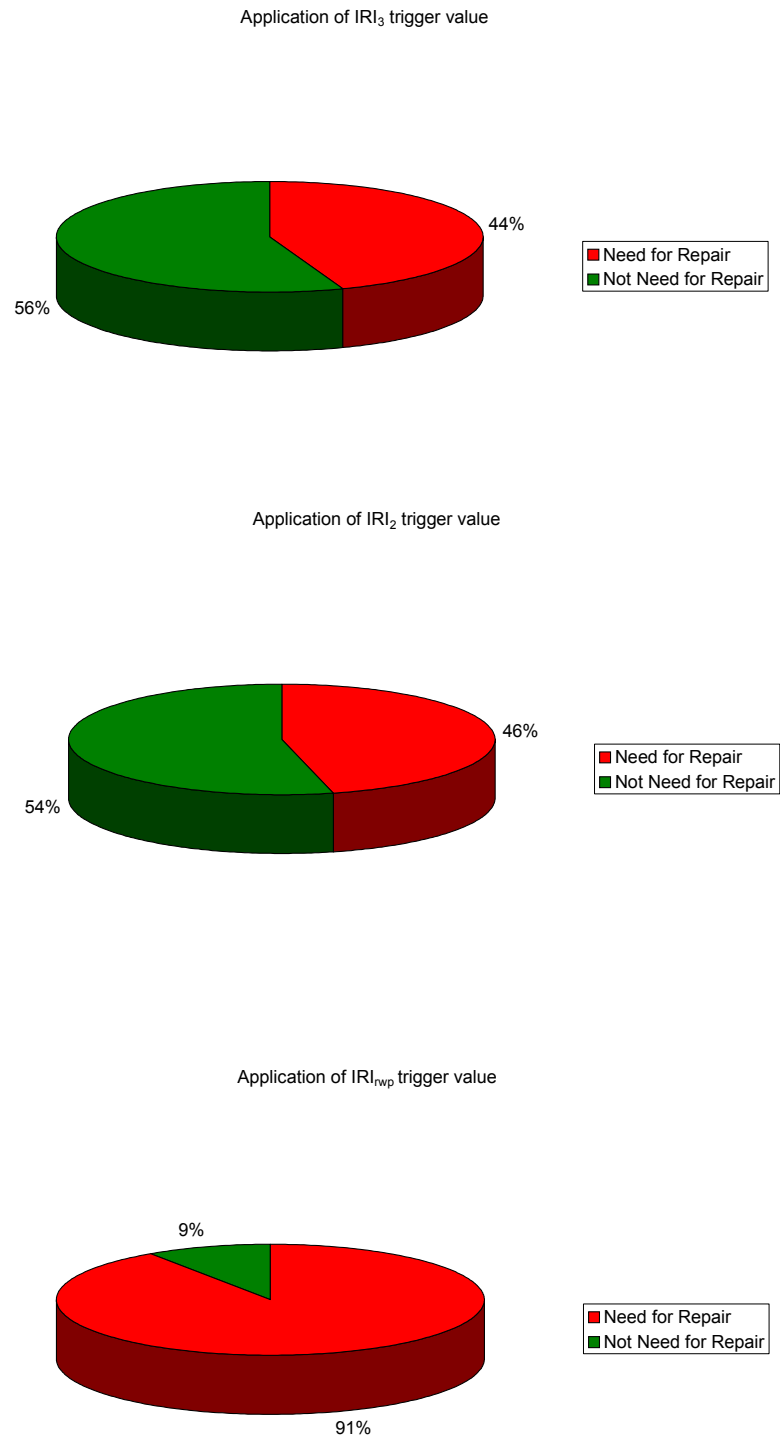
**FIGURE 2** Linear prediction model of the three IRI approaches based on MPR



**FIGURE 3 NR versus MPR**



**FIGURE 4** Linear prediction model of the three IRI approaches based on NR



**FIGURE 5** Percentages of the motorway pavement surface reflecting the need for repair