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Investigation of Critical Aspects of Roughness Assessment for Airfield Pavements

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Abstract: One of the main priorities of airport authorities is to maintain a high level of serviceability of runway pavements due to the high safety requirements for aircraft at high speeds. Accordingly, the assessment of the functional condition of airfield pavements is crucial for the proper operation of an airport. The most critical functional parameter appears to be pavement roughness. It characterizes the condition of the runway surface and is directly related to the safety of aircraft flights, as it affects the handling characteristics and braking performance of the aircraft, the increase in operating costs, and the wear of the aircraft. Worldwide, there are several indices for assessing the roughness of airfield pavements. This study aims to compare some of these indices to assess their ability to capture the characteristics of airfield pavement roughness. For this purpose, roughness data were collected along a runway with flexible pavement at a regional airport in southeast Europe and corresponding indices were estimated. The analysis of the data leads to the most efficient index for assessing the roughness of airfield surfaces to date. However, the need for a new index that expresses the response of the aircraft remains a critical issue.

Keywords: airfield pavements; runway; roughness indices; flexible pavements

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1. Introduction

Maintaining a high level of functional characteristics of an airport's runway is a top priority for airport authorities because of the very high speeds that aircraft develop during takeoff and landing. Although the above requirements also apply to road pavements, they are even more stringent for airport pavements because airport operations require a high level of safety. Often the condition of an airport pavement can lead to accidents with serious consequences, while records of aircraft accidents in various periods between 2003 and 2023 show that most aircraft accidents occurred during the landing phase [1–3]. Therefore, maintaining a high level of serviceability and safety is a key issue for an effective airfield pavement management system.

In practice, however, it is impossible to maintain the condition of the pavement as it was when constructed. This is because factors such as weather conditions, traffic, and material aging wear down the pavement over time, reducing its load-bearing capacity and degrading its functional properties [4–7]. To maintain a pavement's serviceability and safety at a high level, periodic testing and measurement of its properties must be performed to evaluate its functional and structural condition so that appropriate corrective action can be taken in a timely manner. The functional or operational condition is evaluated by determining the surface quality characteristics of the pavement that affect the aircraft ride quality. These characteristics mainly concern the roughness of the pavement, which is measured on site using special equipment.

Roughness of airfield pavements is not defined by perceived ride quality or passenger discomfort [8], since the level of discomfort is low, and the time of exposure is limited to a few seconds. On the other hand, the stress on aircraft components, reduced braking efficiency, and visibility of cockpit instruments can affect the safe operation of an aircraft [8].

Roughness is a very important quality characteristic of the pavement surface. It characterizes the condition of the pavement surface and is directly related to the safety of aircraft flights, as it affects the ride and braking quality of the aircraft, the operating costs, and aircraft wear [8–11]. Therefore, the timely and appropriate determination of roughness through various measurement methods, as well as the application of various analytical methods to evaluate the pavement condition and draw conclusions, is necessary to have a comprehensive and sound strategy to maintain the operational condition of airfields.

Several researchers have addressed the airfield pavement roughness assessment using different indexes, such as the International Roughness Index (IRI), the Boeing Bump Index (BBI), the Straightedge index (SE), and vertical acceleration. For example in [11], through the roughness assessment of a runway profile in 100 m sections using the IRI, BBI, and the cockpit vertical acceleration, it was found that the IRI was very poorly correlated with the other indexes, while a better correlation was obtained between BBI and cockpit vertical acceleration. Moreover, a very high correlation was succeeded between the IRI and BBI, after omitting profiles characterized by long wavelengths roughness (>40 m). However, this study did not include the SE and the vertical acceleration at the center of gravity of the aircraft.

It is noted that the range of wavelengths that affect aircraft response is wider than the one for road vehicles and it includes long wavelengths due to the high speed of travelling and the distance between the front and rear landing gears [11]. The model used to estimate IRI can detect a limited range of wavelengths, from 1.3 m to 30 m. However, the BBI procedure considers long wavelengths of up to 120 m, since it is believed that wavelengths greater than 120 m do not contribute to dynamic airplane response or negatively impact the airplane [8].

The use of the straightedge index has been studied in [12], where profile data from the measurement performed at sixteen airports with an inertial profiling device were used, both for asphalt and concrete pavements. The index values were calculated using computer simulations of two types of straightedges, four different straightedge lengths, and two different procedures for finding the maximum profile deviations from the straightedge. From the analysis, relationships between the index values for different straightedge configurations have been developed, which serves in favor of comparing specifications for different straightedges.

The IRI, BBI, SE, and vertical acceleration at the cockpit indexes have also been used during the roughness assessment of runways in southern Africa and Australia, as stated in [13]. This research focuses on the significance of the existence of appropriate specifications for evaluating the acceptance of a pavement in terms of roughness, while no correlation between the used indices was investigated.

In practice there are several indices that are used worldwide by different airport authorities to make informed decisions on corrective actions in terms of airfield pavement maintenance strategies. For example, the IRI has been extensively used for roughness assessments of airfield pavements in Canada, Mexico, Italy, Brazil, and South Africa [13–18], although its use is not recommended by the International Civil Aviation Organization (ICAO). In addition, IRI thresholds are established in terms of Airfield Pavement Management Systems (APMS) to determine the functional condition of pavements and to plan future interventions [18]. On the other hand, the IRI is not approved by all airport authorities, since it is believed that this index is not appropriate for assessing airfield pavement roughness, in case irregularities characterized by long wavelengths are observed [11,19]. In the meantime, there is ongoing research on optimizing the IRI parameter [20]. On this basis it seems that there are contradictory assumptions regarding the applicability of this index. In addition, the Federal Aviation Administration (FAA) proposes the use of the BBI for roughness assessment [8], while the ICAO proposes the straightedge indices [21].

Another approach is to evaluate the impact of the roughness of a measured runway profile by simulating the response behavior of aircraft [9].

However, although researchers are making great efforts to study the roughness of airfield pavements, the existence of various indices used by airport authorities can pose a problem in assessing roughness. As mentioned earlier, many studies focus on different indices (e.g., IRI, BBI, etc.) without establishing a standard framework for comparison or application to airports. Research could further investigate the effectiveness of these indices in predicting operational impacts and, better still, select the best index for assessing the roughness of airfield pavements.

With this background, the objective of the present work is to study the evaluation of the roughness of the surface of runways at airports in the context of assessing their operational condition and to determine the roughness characteristics that influence the response of aircraft. Methodologically, this study first includes an overview of the indices that can be used to assess the roughness of airfield pavements and then a comparative-correlation analysis between these indices to determine whether they can capture the characteristics of airfield pavement roughness. Roughness data of the flexible pavement along a runway of a regional airport in southeast Europe were collected and used for the analysis.

Since the suitability of roughness indicators has not yet been clarified in the international literature, the question arises for airport authorities as to which roughness index is best suited to optimize the management of airport pavements for the benefit of airport operations. The aim of this study is therefore to evaluate the effectiveness of the roughness indices investigated and to make a recommendation for the best existing index for assessing the roughness of airfield pavements.

2. Evaluation Methods

2.1. Roughness Indices

There are several indices that have been used worldwide for roughness assessment of airfield pavements. In this section, the indices that have been used in the framework of the present research are briefly presented. It is noted that all of these indices can be calculated using ProFAA 3.0.2, a software that has been developed by FAA for roughness assessment [8], in order to evaluate the pavement surface profile and the impact of roughness on aircraft response. A profile is a two-dimensional slice of the road surface, taken along an imaginary line [22]. If the line is following the road direction, the profile is determined as a longitudinal profile [23].

It is noted that, according to the American Society of Testing and Materials' (ASTM) definition [24], roughness corresponds to the deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage, for example, longitudinal profile, transverse profile, and cross slope [22,23]. In the context of the present study, the collected roughness data correspond to the longitudinal profile of an airfield pavement.

2.1.1. Boeing Bump Index (BBI)

BBI is an index that has been developed by the FAA and it is based on the Boeing Bump Method (BBM) [25]. The basis of the BBM is to use a virtual straightedge between two points on the longitudinal elevation profile of a runway and measure the deviation from the straightedge to the pavement surface. The procedure reports "bump height" as a maximum deviation from the straightedge to the pavement surface, while "bump length" is the shortest distance from either end of the straightedge to the location where the bump event is measured (Figure 1). The BBM considers maximum straightedge lengths (wavelengths) up to 120 m.

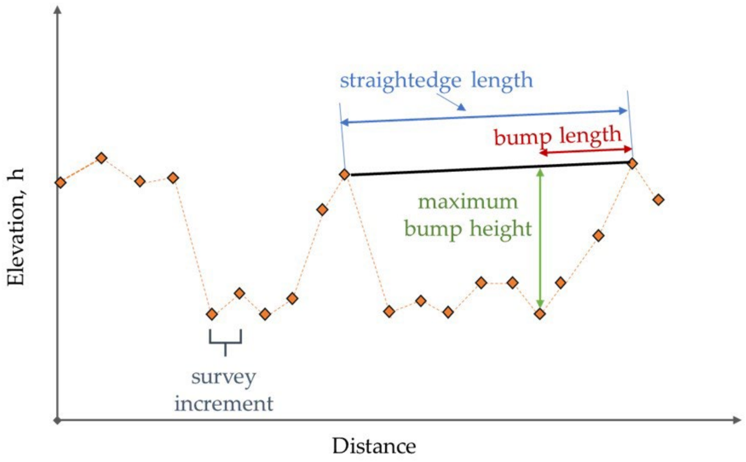


Figure 1. Schematic of bump height measurement [8].

According to the bump height and bump length of a single even bump, pavement roughness can be evaluated as Acceptable, Excessive, or Unacceptable, as shown in Figure 2.

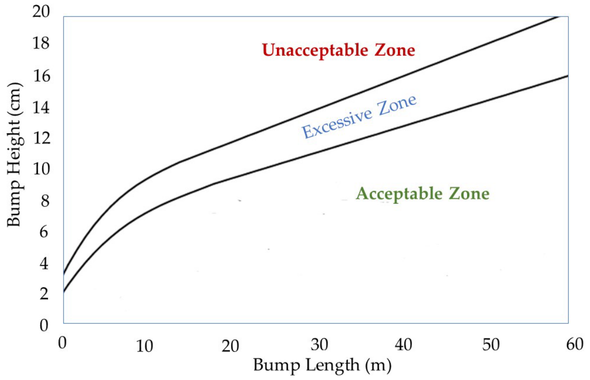


Figure 2. Roughness evaluation for single event bump [8].

Since implementing the BBM to a pavement profile could be a time-consuming and tedious task by evaluating each point in the profile for all possible straightedge lengths, the FAA created the BBI. BBI is determined through the following steps:

(a) For a selected sample point in the profile, the bump height and bump length for all straightedge lengths is computed;
(b) For each straightedge length, the limit of the acceptable bump height (upper limit of the acceptable zone) for the computed bump length is computed;
(c) For each straightedge length, the ratio (measured bump height)/(limit of acceptable bump height) is computed;
(d) Steps (a) through (c) are repeated for all sample points in the profile.

The BBI for the selected sample point is the largest of all values computed in step (c).

In terms of BBI value, a pavement can be classified according to its roughness as belonging to acceptable, excessive, or unacceptable evaluation zone (Figure 3). It is noted that the classification is based on the BBI and the bump length.

In case BBI is less than 1.0, roughness is evaluated as corresponding to the acceptable zone, in which operations are acceptable for all aircraft. When BBI is greater than 1.0, roughness belongs either to the excessive or even to the unacceptable zone. In the excessive zone, immediate repair actions are recommended, since roughness of this magnitude may affect the instrument control in the cockpit and consequently the safe operation of the aircraft. Roughness in the unacceptable zone requires immediate closure of the pavement and restoring roughness to an acceptable level. BBI is calculated automatically in ProFAA, the software that has been developed by FAA for roughness assessment.

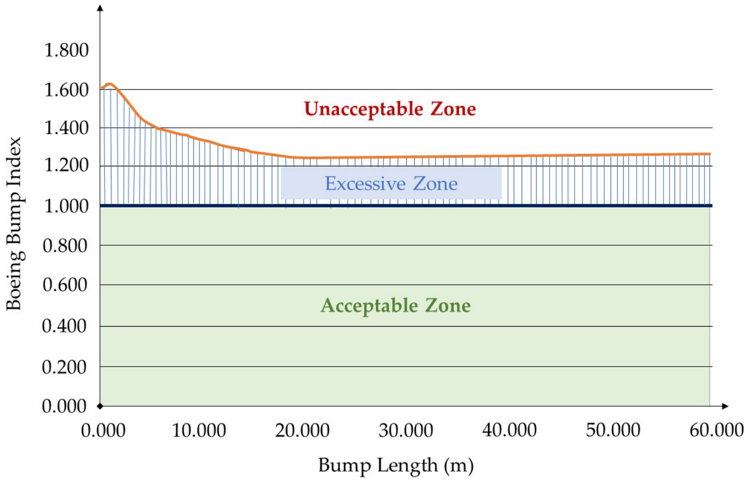


Figure 3. Roughness acceptance criteria based on BBI [8].

2.1.2. International Roughness Index (IRI)

IRI is a mathematical representation of the accumulated suspension stroke of a vehicle, divided by the distance traveled by the vehicle during a test. The IRI is calculated from a measured longitudinal road profile using a quarter-car simulation and has units of slope (Figure 4). The basis of the IRI development was the NCHRP project in the late 1970s, described in the NCHRP report [26], and following standardization procedures of the World Bank [27,28], during the International Road Roughness Experiment (IRRE) performed later in Brazil [29].

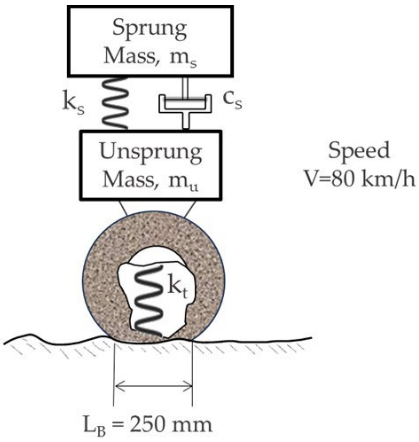


Figure 4. Quarter-car model [28].

The IRI index expresses the roughness that affects vehicle response and is useful when relating roughness to the overall vehicle operating costs, ride quality, dynamic wheel loads, and general road surface conditions. An IRI value of 0 m/km in a given sample interval means that the pavement surface is rather flat. Theoretically there is no upper limit of IRI values, although in practice values exceeding 8 m/km refer to road surfaces which are impassable, except in cases where the movement speed is too low. For airport runways the value of IRI ranges from approximately 0.5 to 2 m/km.

IRI has gained international recognition and acceptance for several reasons. In particular, the IRI has become a standardized measure for evaluating the roughness of road pavements that is used in various countries and by organizations such as the World Bank and the American Association of State Highway and Transportation Officials (AASHTO). Its standardized methodology enables uniform comparisons of pavement conditions across countries and regions, facilitating international studies and assessments. Overall, the international dimension of the IRI is characterized by its widespread acceptance, its application in different contexts, and its role in improving global pavement management practices [13–18,30].

The effectiveness of the IRI in evaluating road pavements has led to the index also being used in many cases to evaluate the roughness of airfield pavements.

2.1.3. Straightedge (SE)

Physical straightedges are usually used for the roughness acceptance of new airfield pavements. During implementation, a straightedge rests on the two highest points of the pavement profile beneath the straightedge as shown in Figure 5. ProFAA simulates the operation of the straightedge by setting one end of the straightedge on a specified profile sample and computing the upper convex hull for all of the profile sample points within the full length of the simulated straightedge. The two highest points in the convex hull become the support points of the straightedge and define a straight line representing the bottom edge of the simulated straightedge [12].

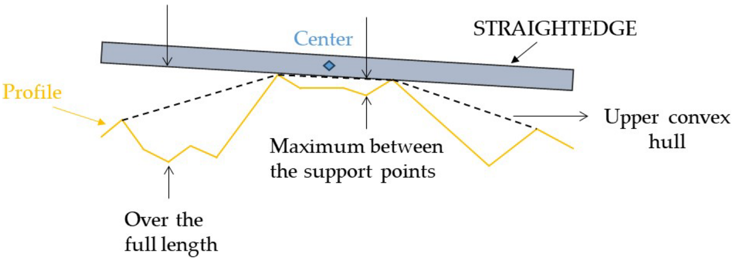


Figure 5. Simulation model of physical straightedge [12].

The vertical distance from the straight line representing the straightedge to each of the profile measurement points below the straightedge is calculated. The maximum value of all vertical distances is given as the maximum deviation from the straightedge over its entire length. A second option allowed in ProFAA is to compute the maximum deviation from the straightedge between the supports.

After estimating the maximum deviation for the first straightedge position along the profile, the reference end of the straightedge is moved one sample point along the profile. The maximum deviation is found, and the procedure is repeated until the specified index length has been covered. The average value of the maximum deviations corresponds to the index value over the specified length. The SE can be estimated for several straightedge lengths, while different criteria have been established according to the length. For example, ICAO requires a straightedge of 3 m long and the deviation is measured over the full length [21].

2.1.4. Root Mean Square Vertical Acceleration (RMSVA)

Roughness of airfield pavements can be assessed by simulating the movement of the aircraft along the runway. By predicting the response of the aircraft to the recorded pavement profile, areas of degraded roughness can be precisely found and ride quality can be accurately quantified. The simulation may be performed for speeds between 10 and 200 knots. A speed of 20 knots is generally recommended for traffic on a taxiway and a speed of 100 knots for runway traffic. Moreover, the aircraft response can be simulated for the following representative commercial aircraft: Boeing 727 and Boeing 747 and Mcdonnell Douglas DC 9 and DC 10. It is important to recognize that by simulating the motion of a long-wheelbase aircraft and a short-wheelbase aircraft (e.g., Boeing 747 and Boeing 727), different areas of roughness can be detected [31].

Based on the above, an index that is also used for roughness assessment of airfield pavements is the Root Mean Square Vertical Acceleration (RMSVA). This index can be estimated for the cockpit (RMSVA CP) and the aircraft center of gravity (RMSVA CG) using ProFAA [9]. According to NASA, it is suggested that the maximum vertical acceleration in the cockpit should not exceed 0.40 g, relating it with the pilot complaints due to runway roughness.

2.2. Research Methodology

For the present research, data collection was performed along a 2.3 km long runway's flexible pavement of a regional airport of southeastern Europe. To evaluate the functional condition of the runway, roughness data were recorded using the Road Surface Profiler (RSP) [32–34], which is a high-speed inertial measurement system (Figure 6).

Figure 6. Measurements on the runway using RSP.

For the selection of the measurements' path, the guidelines of the FAA were considered. According to FAA [8], measurements of runway surface profile must be performed along the centerline of the runway and at lateral distances that approximate the paths of the aircraft expected to use the airport. A lateral distance of about 3 m right and left of the centerline can effectively address airplanes of Airplane Design Group (ADG) II and III, while a lateral distance of about 5.2 m right and left of the centerline can address airplanes of ADG IV, V and VI. On this basis, for the present investigation, measurements along the centerline and at a lateral distance of 3 m (left and right of the centerline) were performed, since it was assumed that most aircraft loads would occur in this area, according to the available traffic data (Figure 7).

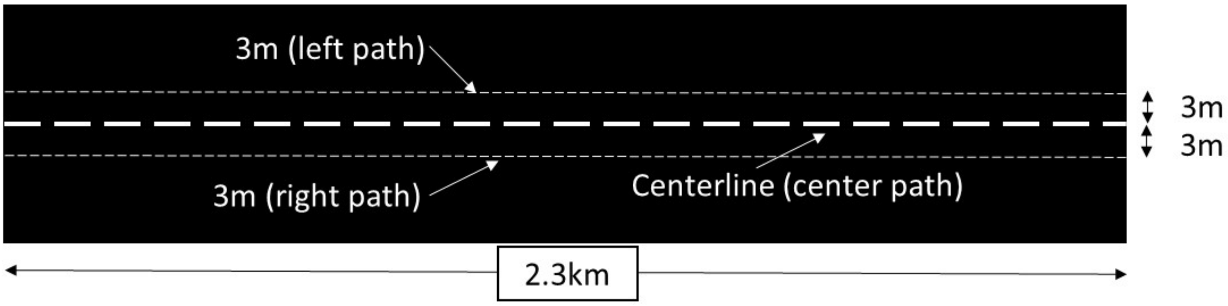


Figure 7. Measurements' paths.

The collected data were then analyzed in order to assess the roughness of the pavements, based on several indices (IRI, BBI, SE and RMSVA), along the three paths of the measurements (left path, center path and right path). The estimation of the abovementioned indices was performed through ProFAA software, which has been developed by the FAA. The analysis included an investigation of potential correlation between the calculated indices, as shown in the methodology layout in Figure 8. By comparing the individual indices for the measurements of the three paths, related results occur. In order to correlate the indices, linear regression analysis and the coefficient of determination R^2 were used. Moreover, the significance of the differences of the same index between measurements of the three paths was checked using *t*-test analysis.

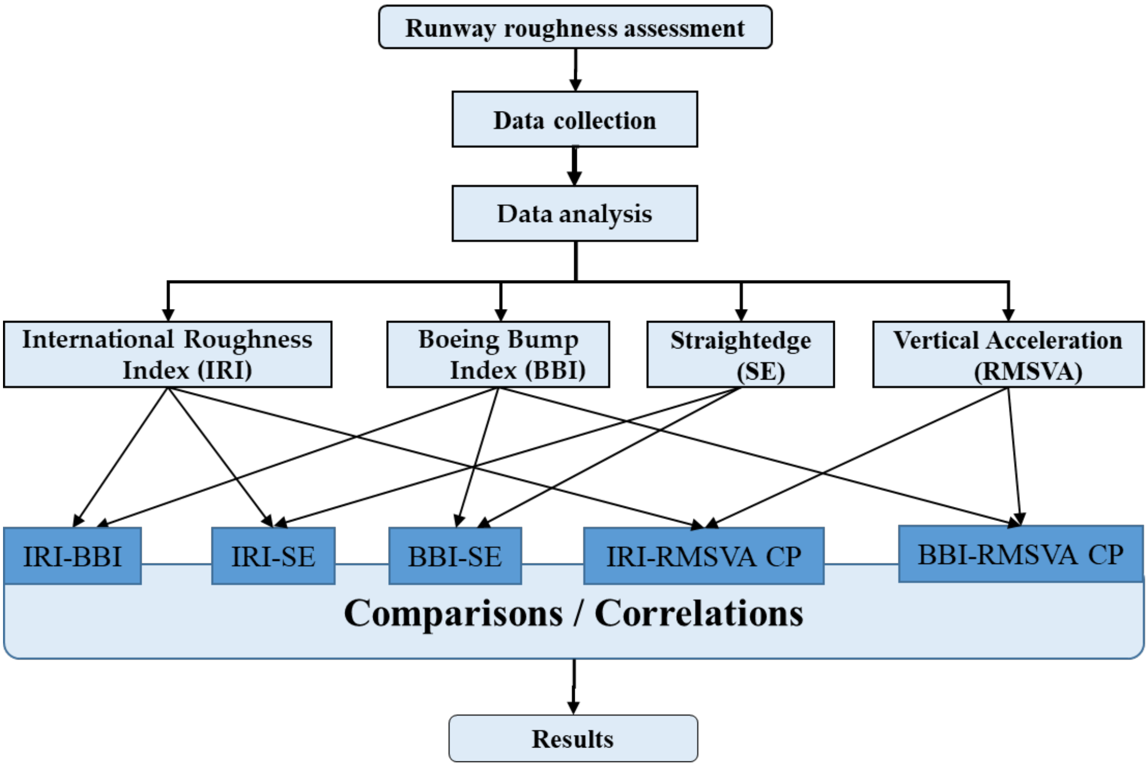


Figure 8. Methodology layout.

3. Results and Discussion

3.1. Estimation of IRI, BBI, SE and RMSVA CP

In the framework of the present investigation the data occurring from roughness measurements were further analyzed in order to calculate several roughness indices that are used for roughness assessment of airfield pavements. On this basis, the entire length of the runway pavement was divided into 51 subsections of the same length (reference length: 45 m), following the procedure implemented by ProFAA, where a minimum section length of 30 m may be considered. With this in mind, the reference section of 45 m was considered as a weighted value, taking into account the different wavelengths that can be captured through the investigated roughness indexes. The outcome of the analysis is presented in Figure 9 for the three paths of the measurements. Figure 9a–d presents the IRI, BBI, SE, and RMSVA CP values, respectively.

According to Figure 9a, IRI presents relatively reasonable values for a runway's pavement, ranging from 0.5–2.5 m/km. As seen in Figure 9b, BBI presents measurement values of less than one for all paths, which is the limit of the acceptable range. This indicates that the condition of the runway can be characterized as good. Moreover, considering SE, the majority of the observed values are below 3 mm, which corresponds to the criteria specified by ICAO for a straightedge length of 3 m that has been used in the analysis. The results of the simulation of the aircraft response (at the cockpit) for the recorded pavement profiles are presented in Figure 9d. For the analysis aircraft, Boeing 727 with a speed of 100 knots was considered. From the RMSVA CP reasonable values, it occurs that the surface condition of the runway is satisfactory.

In order to check the significance of the differences of each index for left, center, and right paths, a *t*-test statistical analysis of paired observations was performed. By using this test, it can be checked whether a sample parameter (for example the mean value) satisfies a hypothesis against an alternative hypothesis. Initially, the null hypothesis is formed, in which the difference of the mean values of an index for two paths is equal to zero. The alternative hypothesis considers that the above difference is not equal to zero. In order to accept the null hypothesis, the critical value ($t_{critical}$) must be greater that the statistic value

(t_{stat}), i.e., $|t_{stat}| < t_{critical}$. The results of the *t*-test analysis for all indices are presented in Table 1.

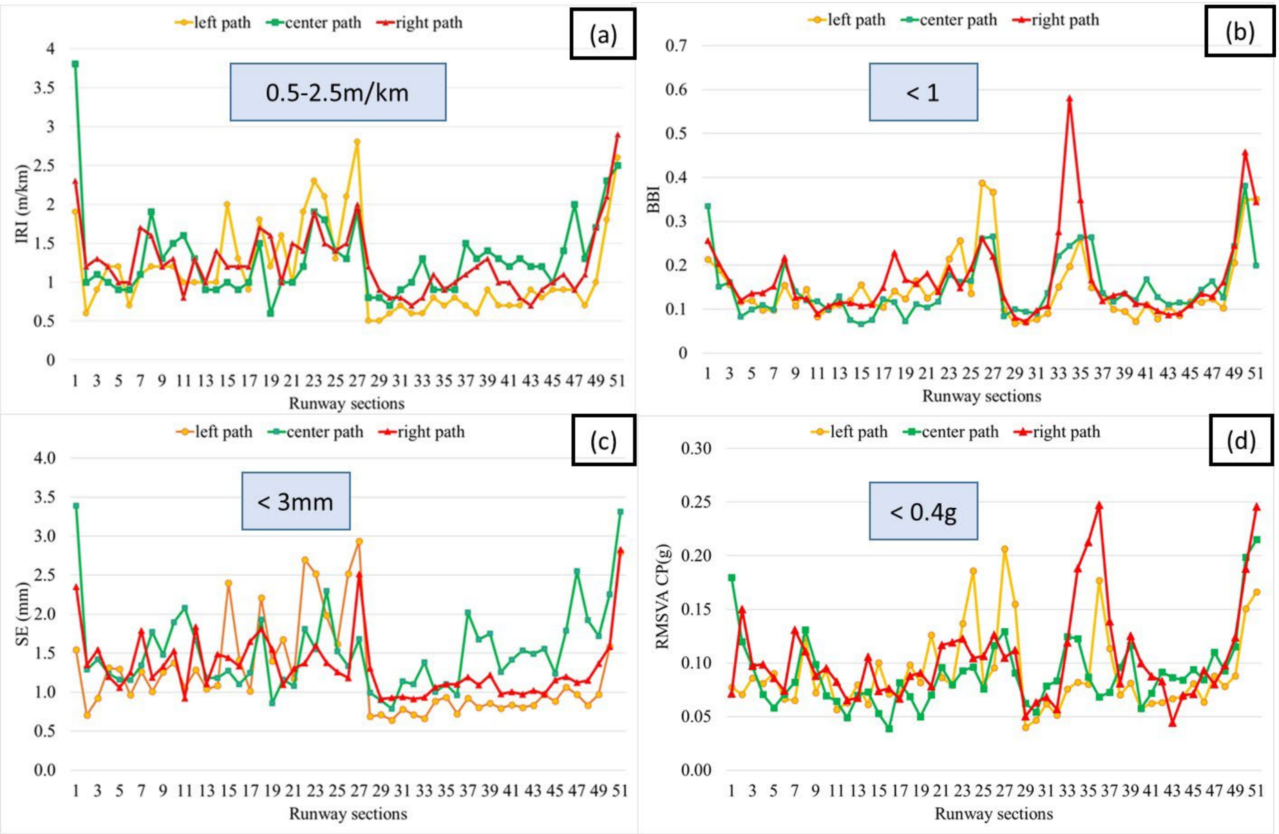


Figure 9. (**a**) IRI, (**b**) BBI, (**c**) SE, and (**d**) RMSVA CP (for left, center and right path).

Table 1. *T*-test results.

Index	Index (Path)	$|t_{stat}|$	$t_{critical}$	Null Hypothesis
BBI	BBI (left)–BBI (center)	0.201	2.009	Accepted
	BBI (center)–BBI (right)	2.171	2.009	Rejected
	BBI (left)–BBI (right)	2.122	2.009	Rejected
IRI	IRI (left)–IRI (center)	2.226	2.009	Rejected
	IRI (center)–IRI (right)	0.719	2.009	Accepted
	IRI (left)–IRI (right)	2.380	2.009	Rejected
SE	SE (left)–SE (center)	2.958	2.009	Rejected
	SE (center)–SE (right)	3.215	2.009	Rejected
	SE (left)–SE (right)	0.939	2.009	Accepted
RMSVA CP	RMSVA CP (left)–RMSVA CP (center)	0.240	2.009	Accepted
	RMSVA CP (center)–RMSVA CP (right)	2.412	2.009	Rejected
	RMSVA CP (left)–RMSVA CP (right)	2.667	2.009	Rejected

The results show that for the pair of BBI values of the left and center paths, the null hypothesis is accepted, while for the other two pairs it is not accepted. Therefore, it appears that the differences in the BBI values of the left and center path are not significant, while the differences in the BBI values of the center and right path and of the left and right paths are important. As far as IRI is concerned, *t*-test analysis showed that only the difference in the IRI values between the center and right paths are not significant. Considering the SE index, it is observed that the differences in the SE values between the left and right paths are not significant. Moreover, it appears that the differences in the RMSVA CP values of the left and center path are not significant, which coincides with the trend of the BBI value.

3.2. Comparative Analysis of BBI, IRI, SE

Since the indices presented significant differences between different paths, the comparative analysis of the indices was performed for each path separately. For practical reasons, in the framework of the present work, comparative charts of the indices for only one path (left path) are indicatively presented, while total results for all paths follow.

Figure 10 shows the comparison between the SE and IRI, Figure 11 shows the comparison between the SE and BBI and Figure 12 shows the comparison between the BBI and IRI. In Figure 10 it can be seen that the SE index results follow almost the same trend as the IRI results. In Figures 11 and 12 it is observed that in sections 33–35 there is a relatively large increase in the value of BBI, which is not depicted through the values of IRI and SE.

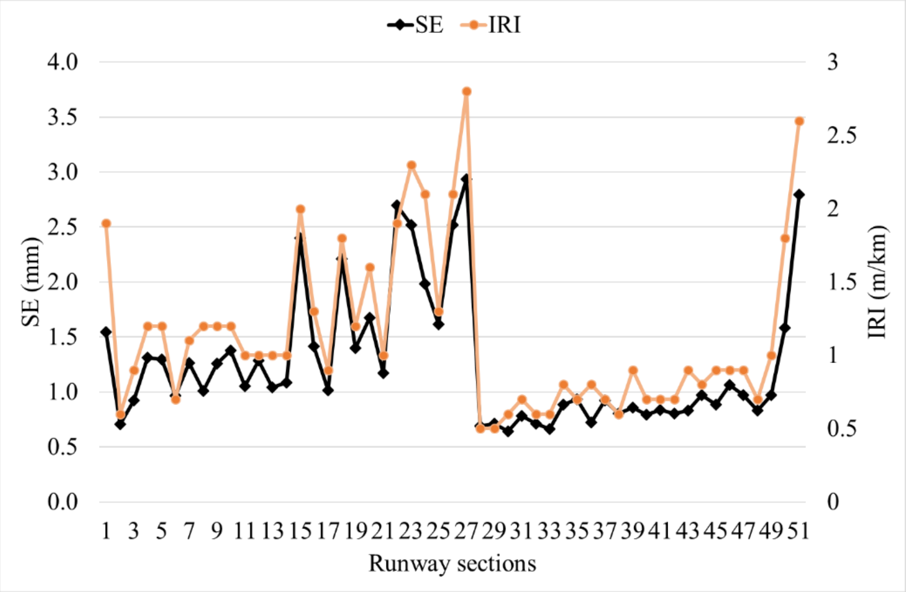


Figure 10. SE and IRI comparison (left path).

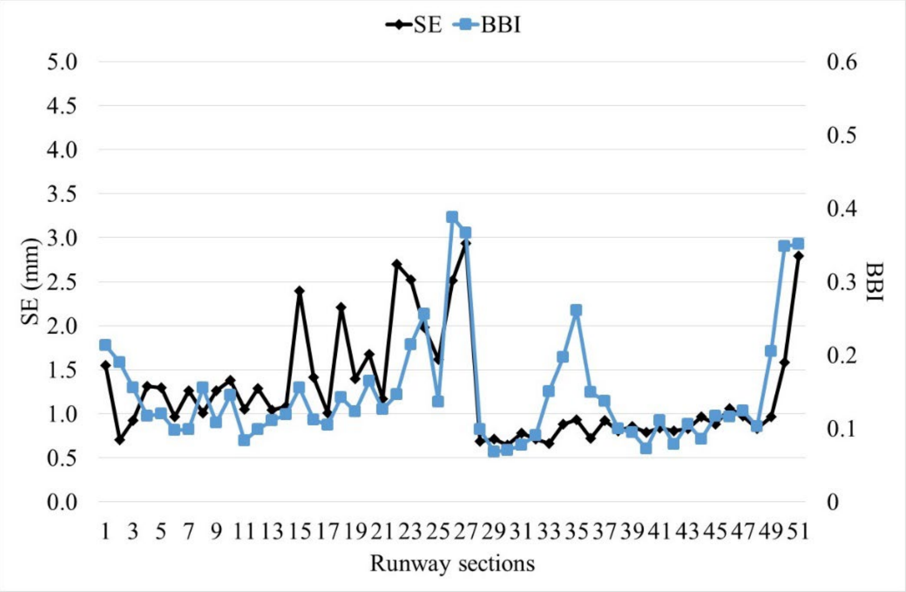


Figure 11. SE and BBI comparison (left path).

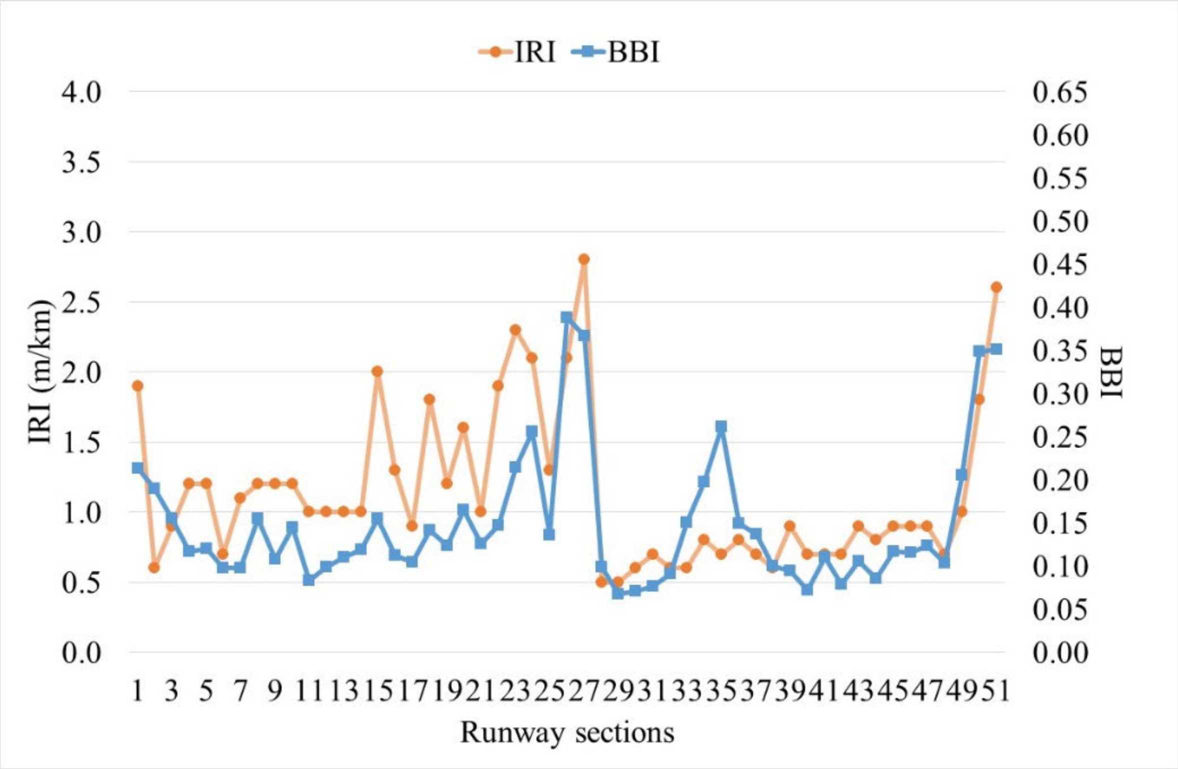


Figure 12. IRI and BBI comparison (left path).

Figures 13–15 present the results of the linear regression between SE-IRI, SE-BBI, and IRI-BBI for the left path, respectively. Moreover, the values of the coefficient of determination R^2 are also presented. The corresponding results for each individual path and for all paths together are presented in Table 2.

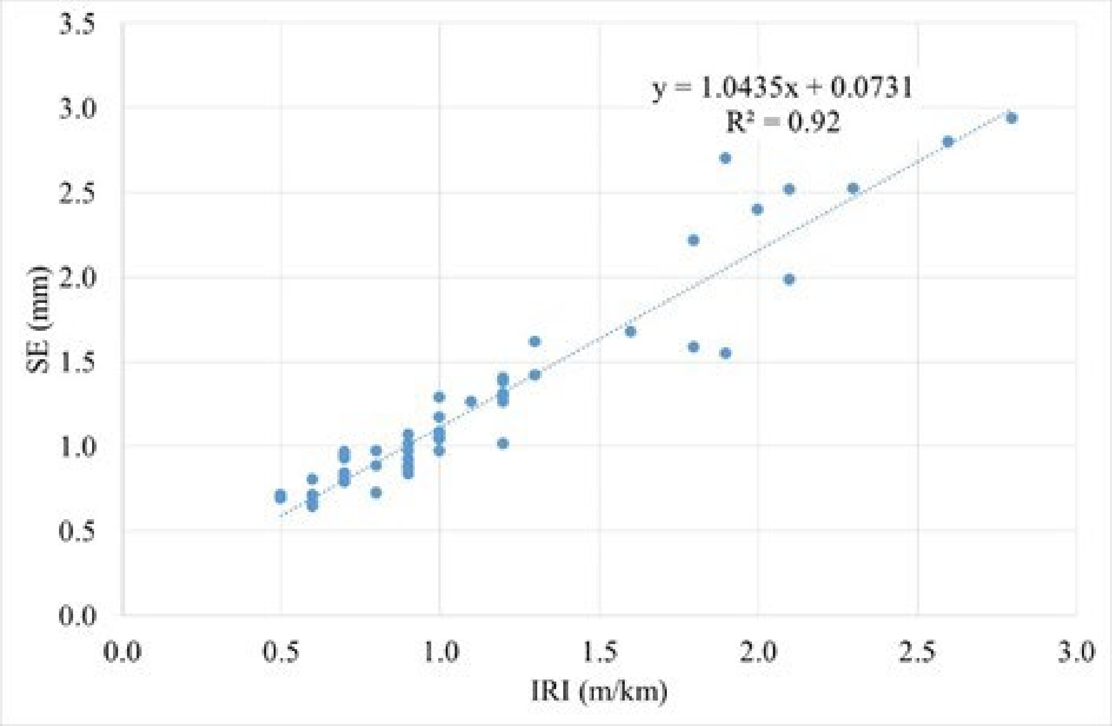


Figure 13. Correlation between SE and IRI (left path).

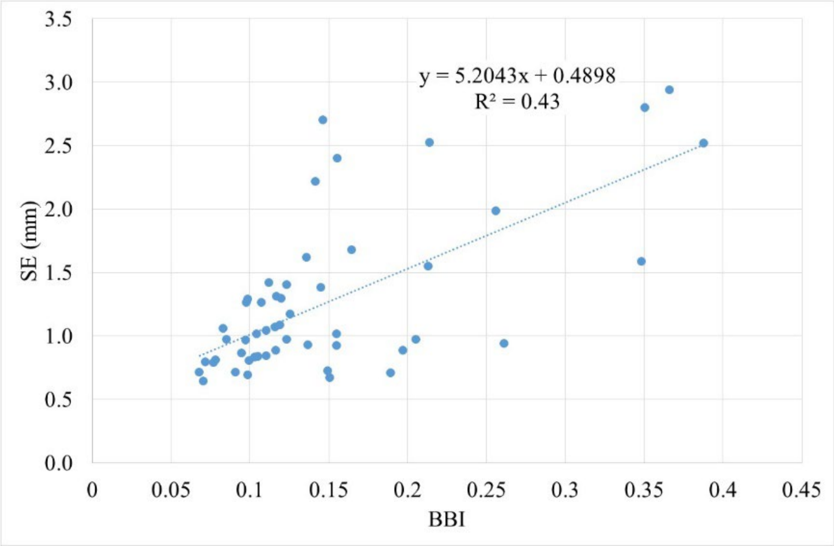


Figure 14. Correlation between SE and BBI (left path).

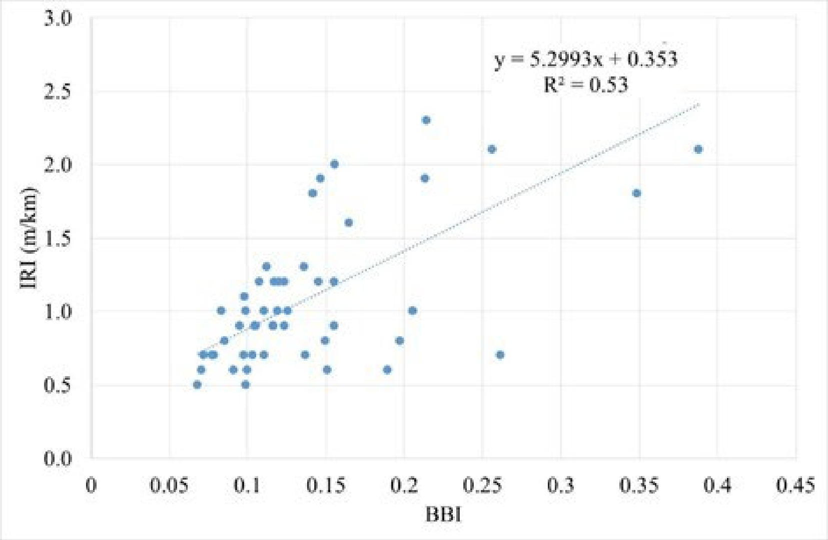


Figure 15. Correlation between IRI and BBI (left path).

Table 2. Values of R^2 for linear regression analysis between SE-IRI, SE-BBI, and IRI-BBI for all paths.

	SE-IRI	SE-BBI	IRI-BBI
Left path	0.92	0.43	0.53
Center path	0.83	0.18	0.37
Right path	0.77	0.10	0.23
All paths	0.84	0.19	0.35

From Table 2 it is observed that IRI has a very good correlation with SE and especially for the left path it has a very high correlation. This occurs because the IRI is mainly affected by the smaller wave lengths of 1.3–30 m. The BBI has a low correlation with SE except for the left path, for which it has a moderate correlation. This may happen due to the fact that the BBI is more affected by the larger wave lengths and not so much by the smaller ones that may affect the SE. It is noted that the estimation of the BBI is based on the procedure presented in Section 2.1.1, which includes straightedge lengths up to 120 m, while for the SE a straightedge length of 3 m has been used. Moreover, BBI has a relatively better correlation with IRI than with SE but not a satisfactory one.

3.3. Comparison Between RMSVA CP and RMSVA CG

In terms of the present analysis, the RMSVA index was also considered for expressing the aircraft response due to pavement roughness. Since this index is estimated both for the cockpit (RMSVA CP) and the center of gravity of the aircraft (RMSVA CG), a comparison between the two indices was initially performed. Figure 16 shows a comparison between the results of the vertical acceleration in the cockpit and the center of gravity of the aircraft Boeing 727 at a speed of 100 knots for the left path of the measurements. It is observed that the RMSVA CP values are greater than the RMSVA CG values. This shows that the cockpit compartment is more sensitive to the effects of roughness than the passenger cabin area, which reinforces the finding that roughness on airfield pavements is more related to flight safety than to passenger comfort.

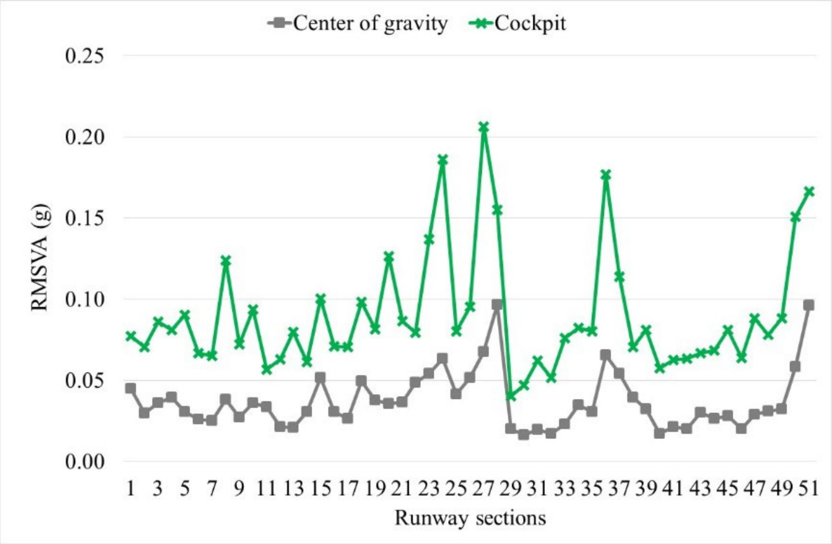


Figure 16. Comparison of RMSVA for center of gravity and cockpit, Boeing 727 speed 100 knots (left path).

A linear regression was then performed between the RMSVA CP results and the RMSVA CG for all three paths of measurements. As shown in Figure 17 there is a good correlation (R^2 = 0.74) between the two indices. It also transpires that the values of the RMSVA CP are about 2.3 times greater than the values of the RMSVA CG.

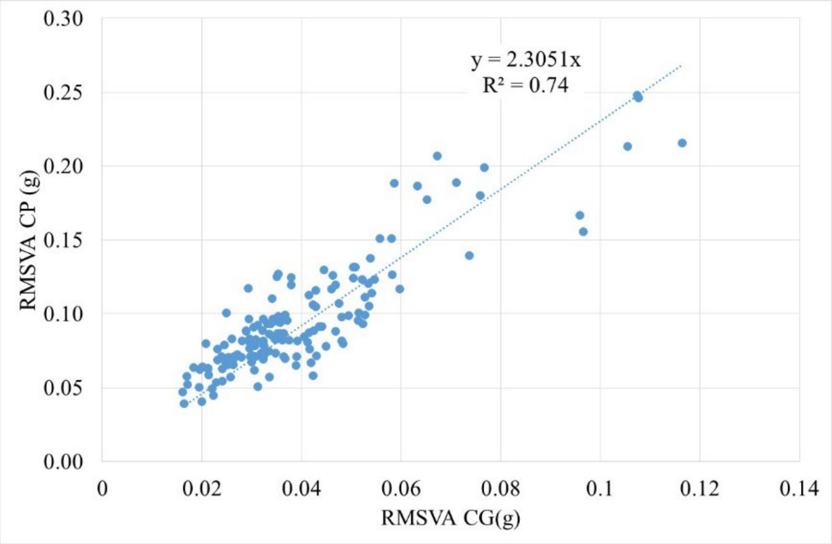
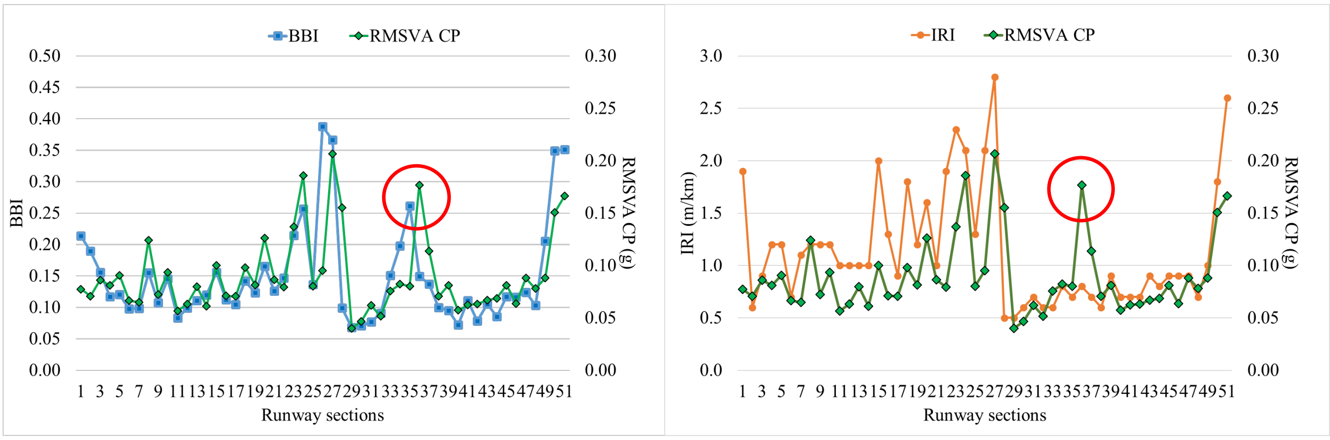


Figure 17. Results of liner regression between RMSVA CP and RMSVA CG (all paths).

It is noted that the RMSVP CP index was selected for the comparative analysis with BBI and IRI index, since it is believed that it consists of the critical vertical acceleration index of the aircraft response.

3.4. Comparative Analysis of BBI and IRI with RMSVP CP

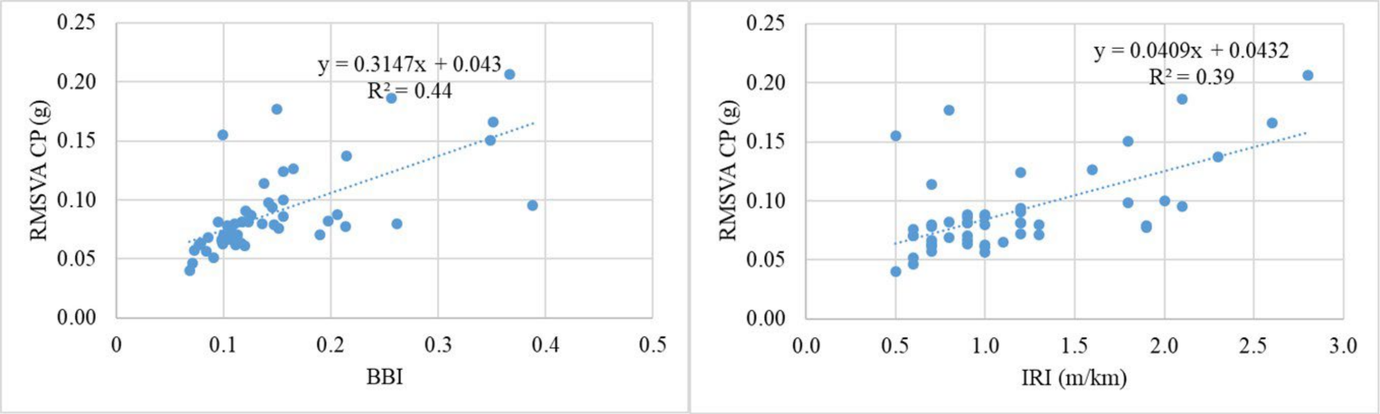
A comparison of the BBI and IRI results with the aircraft response simulation results (RMSVA CP) is then made (Figure 18). As shown in Figure 18a, the vertical acceleration presents a similar trend with BBI. However, according to Figure 18b, in the region where the vertical acceleration presents a peak value (marked with a red circle), IRI presents a relatively low value, which indicates that IRI cannot identify this event. On the other hand, for the same region, BBI identifies the area of poor aircraft response (marked with a red circle), as shown in Figure 18a.



(**a**) (**b**)

Figure 18. Comparison of: (**a**) BBI and RMSVA CP (left path), (**b**) IRI and RMSVA CP (left path).

Figure 19 presents the correlation of BBI and IRI with the RMSVA CP for the left path, while Table 3 summarizes the values of the coefficient of determination R^2 from the linear regression of the corresponding indices, for each path individually, and also for the three paths together.



(**a**) (**b**)

Figure 19. Correlation between: (**a**) BBI and RMSVA CP (left path), (**b**) IRI and RMSVA CP (left path).

Table 3. Values of R^2 for linear regression analysis between BBI-RMSVA CP and between IRI-RMSVA CP for all paths.

	BBI-RMSVA CP	**IRI-RMSVA CP**
Left path	0.44	0.39
Center path	0.54	0.52
Right path	0.47	0.18
All paths	0.48	0.36

Both Figure 19 and Table 3 show that both indices (BBI and IRI) do not correlate particularly well with RMSVA CP for all paths although BBI generally has a better, but not satisfactory, correlation.

4. Conclusions

From the present study, it is clear that there are several indices for evaluating the roughness of airfield pavements which can provide engineers with different information about the actual condition of the pavement. In general, the IRI represents the simulation of the response of a single vehicle suspension system. In this case, the results have shown that the IRI analysis is not representative of the aircraft response and that it does not detect the longer waves that are important for the aircraft response. Thus, the present study confirms that IRI analysis is not recommended for use on airfield pavements, as also shown by international research and related experiences [11].

In particular, SE showed a very high correlation with IRI, indicating that IRI is mainly affected by smaller wavelengths, but SE showed a low correlation with BBI, indicating that BBI is not particularly affected by the smaller wavelengths. It is suggested that SE could be useful for evaluating new pavements (where long waves have not yet been generated by aircraft operations), but due to its limited size, it appears that it cannot detect all waves that affect aircraft responses.

On the other hand, BBI detects areas of degraded roughness mainly due to longer wavelengths but does not correlate particularly well with aircraft response. Since this indicator only evaluates the wavelength and width of an event, it can only evaluate one event/incident at a time. However, the poor aircraft response may be due to a series of consecutive events, any one of which could be deemed acceptable by BBI.

It should be noted that the results of the present study are based on measurements taken once on a specific runway, using the procedures described in [31] in order to achieve the highest possible accuracy. Furthermore, it is assumed that possible deviations of the measured surface profile resulting from the repetition of roughness measurements would not change the results of the present study. This aspect is based on the fact that all the indices used depend on the measured profile and are not measured independently, so it is assumed that the study of the correlation between them is not affected by any inaccuracies in the measurements.

All the above conclusions are consistent with the results of previous studies, also referred to in this paper, and produce evidence in support of the statement that the BBI can be considered the most efficient index for assessing the roughness of airfield pavements to date. However, there are some issues that limit its effectiveness as mentioned above. For this reason, it is felt that new indexes related to aircraft response under real operating conditions should be incorporated in practical evaluation tools. In this direction, further consideration must be given to the real-world nature of aircraft movement, as aircraft typically move at a wide range of speeds during takeoff and landing, not only accelerating but also decelerating. To this end, relevant research is currently underway [35] which also considers the assessment of roughness in the presence of multiple bumps. Furthermore, the analysis of pavement roughness using various indices is crucial for decision-making in airfield management. If decision makers rely on a particular roughness index, they may overlook the nuances that other indices present. For example, if two sections are classified as “acceptable” based on one index, but one has a significantly poorer ride quality according to another index, this may lead to inappropriate prioritization for maintenance or rehabilitation. It is therefore considered that the use of a multi-index approach could facilitate the assessment of airfield pavements. This can help us to make more informed decisions that take into account different aspects of pavement quality. To achieve this, the implementation of emerging technologies [36,37] can optimize the airfield pavement surface monitoring procedures.

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