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The evaluation of runway surface properties: a new approach

D'Apuzzo Mauro[a], Festa Bruna[b]*, Giuliana Giovanni[b], Mancini Laura[b], Nicolosi Vittorio[c]

[a]*University of Cassino, Via di Biasio, Cassino 04023, Italy*
[b]*University of Naples "Federico II", Via Claudio 21, Napoli 80121, Italy*
[c]*University of Rome "Tor Vergata", Via del Politecnico 1, Roma 00133, Italy*

Abstract

The assessment of surface characteristics of runway pavement plays a key role in a modern APMS as it affects, on safety of aircraft operations and user riding comfort. In this paper a more cost-effective approach to develop empirical degradation models which is based on the evaluation of the transversal variability of surface properties of a runway is proposed. The methodology is based on the evaluation transversal distribution of the equivalent coverages derived from the aircraft traffic data. Preliminary results seem to indicate that the approach may represent a viable tool in evaluating the roughness and friction progression.

Keywords: runway; skid resistance; roughness; deterioration models.

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1. Introduction

The assessment of surface characteristics of runway pavement plays a key role within quality control of works [1] and in a modern Airfield Pavement Management System (APMS) as it affects, on one hand, safety of aircraft operations and user riding comfort on the other.

In detail, skid resistance on runway is a critical safety concern, as it affects stopping distance and directional control of aircraft and plays a major role in overrun and veer-off accidents (excursion accidents) occurring during takeoff or landing phases [2]. Airport pavement surface smoothness affects safety of aircraft operations and comfort of passengers. Runway roughness interferes with safe operations and structural integrity of aircraft in several ways:

- inducing excessive pitch and roll motions which may interfere with aircraft control;

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* Corresponding author. Tel.: +39-081-768-3373; fax: +39-081-768-3946.
E-mail address: festa@unina.it

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- heightening inertial forces and inducing structural damage and fatigue phenomena in aircraft structural components;
- causing on-board vibrations, which prevent pilots from accurately reading instruments during takeoff;
- reducing tire/pavement contact, which may affect anti-skid braking system and degrade aircraft stopping performance.

The airplane suspension systems emphasize the above mentioned phenomena, as they are designed primary to absorb energy expended during landing, and therefore they have a low capacity to dampen the impact of surface irregularities. Roughness has therefore to be measured and/or evaluated during airport pavement life, and compared with standards that specify when corrective actions have to be undertaken to restore surface smoothness [3, 4].

On the other hand, the increasing airport traffic is making the planning and the execution of pavement rehabilitation projects a demanding task. Airport Pavement Management Systems (APMS) may offer an effective solution for the optimization of the maintenance interventions in view of minimizing costs and traffic disruption (i.e. runway closures).

One of the key elements for managing airport pavements is to capture accurately and to forecast the performance of the facility through well established deterioration models. Airport authorities are in need of a set of reliable runway deterioration (RD) models to assess short-term maintenance needs (i.e. two /five years).

RD models are generally developed empirically whose performance indexes (for example roughness, friction, etc.) depend on several independent parameters (for example traffic loading, climate condition, pavement type, subgrade condition, etc.).

A sound deterioration model should incorporate:

- physical principle that reflects the deterioration mechanism;
- relevant variables affecting the deterioration process;
- a rigorous statistical approach to estimate the model.

Generally, only one data point is measured each test session, so the available data, in the early years, is very low, unless we use data from several runways. But in this latter case, the number of relevant variables in the RD model increases (i.e. material information, environmental effect, etc. have to be included); furthermore we have another issue, "heterogeneity", which can be defined as the difference of performance across several facility segments or different facilities.

In this paper, a new approach, for developing runway friction and roughness deterioration models has been proposed in order to increase the goodness of estimate of model parameters and to introduce independent variables that capture exhaustively factors involved in deterioration phenomena.

In detail, an independent variable defined as the number of equivalent coverages is introduced to represent better the traffic impact on friction and roughness deterioration; furthermore, a new procedure for carrying out and analyzing friction tests and roughness measurements has been proposed, as described below.

Finally, a case study is illustrated, in which the proposed approaches are applied to experimental data measured on the runway of G. B. Pastine airport in Rome and optimal policy for measurement sampling has been investigated in order to reduce the number of data necessary to obtain reliable empirical degradation models.

2. Methodology Description

According to the proposed methodology, traffic related factors have been assumed as the main independent variables affecting the deterioration of friction and roughness.

Although deterioration models often take into account the traffic volume (i.e. number of vehicle passes or aircraft departures) [5, 6], the degradation of pavement surface characteristics is greatly related to the number and intensity of tangential (friction) and vertical (roughness) stresses applied by wheels to the pavement. Therefore in this study it was proposed to model friction and roughness deterioration as function of number of equivalent coverages (ECs), and not simply as a function of the number of aircraft movements on the runway, in order to take into account the different damage induced by different aircraft gear according to a specific runway surface property. Because of the transversal distribution of aircraft gear passages, ECs are transversally varying along the cross-section of a runway and therefore the differential degradation of a specific surface property can be captured by performing several measurements along different transversally spaced longitudinal alignments [7].

As a matter of fact, the framework suggested for developing the models could be summarized as follows:

- runway profile measurements and friction tests are carried out along several longitudinal paths in a single test session;
- experimental results of friction tests and profile measurements are analyzed for localizing homogeneous sections;
- number of equivalent coverages (ECs) in the runway cross section points are calculated from traffic and pavement-related input data (annual aircraft movements, traffic spectra, aircraft lateral wandering, wearing course age);
- for each homogeneous section, friction and roughness values are plotted versus ECs and regression models are derived.

In the followings, details on the methodology proposed are reported.

2.1. Surface Properties Measurement and Evaluation

As far as the skid resistance measurements are concerned, regardless the friction measuring device employed, pavement macrotexture should be also collected in order to express skid resistance results on a common basis, by means of the International Friction Index model [8, 9].

As far as runway roughness evaluation is concerned, there is a general approach according to which roughness properties of a runway pavement surface can be divided into two main components [10]:

- a steady or stationary component that can be described by an "average roughness level";
- a transient or isolated component that can by identified as a "bump" or a "depression".

It is worth to be noticed that this approach has been confirmed in a recent FAA circular [11] which is based on the well known "Boeing Bump" method described in [12] however, no clear and sound procedures on bump detection are reported and, up to now, there is no general consensus on how the transient component can be identified and separated by the steady one. In addition, it is still not clear to what extent a sequence of isolated roughness events can be separately analyzed or has to be regarded as a unique steady roughness section.

On the other hand, it has also to be highlighted that it remains difficult to unambiguously apply the concept of stationarity to airfield pavements even if these latter may appear stationary since, as a matter of fact, the aircraft continuously changes speed during normal takeoffs and landings and the frequency of the disturbances experienced by the aircraft changes continuously as well. However if speed profile of aircraft operations can be divided in several section along the runway stationarity may be sought in order to aggregate data for pavement monitoring purposes.

As far as the detection of localized roughness is concerned, several algorithms have been proposed in technical literature [13, 14, 15], however, it has to be highlighted that none of them has been tested with reference to runway pavements. Among the several methods available, the approach based on the Mean Square (MS), evaluation of profile spatial vertical acceleration, has been employed within this study [13, 14, 16].

2.2. Detection of Homogeneous Section

In order to reduce the number of collected records, with the lowest possible loss in accuracy, the data aggregation has to be carried out; it is intended to facilitate monitoring of airport facilities and to improve data analysis.

Many procedures have been introduced till now to identify part of measurement series that can be considered homogeneous (or a stationary time series) and to address the problem of segmentation [16, 17, 18, 19], although they have been mainly applied to rural or urban roads. Among the available segmentation algorithms, the Dichotomic method, proposed by Lebas et al. [20], has been used in this study.

As far as the friction measurements evaluation is concerned, the localization of the homogeneous friction length (over each measurement path) was based on a preliminary identification of four zones reflecting the different landing phases (see Table 1). Within each zone, the segmentation algorithm to detected homogeneous sections has been applied and friction deterioration has been modeled according to a critical cross strip (CCS), that covers the whole cross section and contains only homogeneous path sections (i.e. inside which there are not break points) and the lowest IFI values [19, 20]. Data, derived from CCS, have been employed to develop regression models linking friction values with ECs.

As far as roughness evaluation is concerned, once that roughness singularities have been removed, in order to identify subsequent homogeneous sections that can be considered as stationary, a runway segmentation technique evaluated on most significant alignments located at 0, 3 and 6 m far away from runway axis by means of the Dicothomic method has been used.

The roughness index on which the homogeneous section identification procedure has been based is the Root Means Square of Vertical Acceleration (RMSVA), evaluated on a 20 m base length, according to the procedure reported in Transport Canada, since this index is not affected by specific vehicle properties such as the IRI, but it can be correlated to other conventional roughness synthetic descriptors such as the RCI and the IRI [10].

2.3. Equivalent Coverages Evaluation

Traffic represents the main independent variable in a pavement degradation model, however it is straightforward to argue that different landing gears may induce different damages when all the other involved variables are kept constant. Therefore, it is necessary to evaluate a criterion to compare the damages caused by different landing gear types.

Following these premises, it was proposed to model friction and roughness deterioration as function of number of equivalent coverages (ECs), obtained as number of coverages multiplied for an equivalency factor; the former represents the number of times that a particular point on the pavement is expected to be stressed by a wheel during aircraft operations; the latter was introduced to take into account the different damages produced by several aircraft types and gears (i.e. main and nose gears).

As far as the friction deterioration is concerned, an equivalent damage criterion, proposed by D'Apuzzo & Nicolosi [19, 21], based on frictional energy developed at tyre-pavement interface, has been employed. This criterion is based on the main assumption, according to which the energy involved in the tyre wear process can be considered equal to that spent to polish the pavement surface. In other terms, it is assumed that the damage induced by tyre on the pavement surface is proportional to the energy dissipated in the tyre wear progression. According to this approach, a damage criterion proportional to the vertical load according to a 1.5 power law has been employed.

As far as the roughness deterioration is concerned, a damage criterion proportional to the vertical load according to a 1 power law has been employed as it has proven to provide a higher correlation.

The coverages in a point of the cross section, produced by aircraft traffic, as observed by Festa et al. [20], depend on the number of wheels and on the position of each gear, on the load and the inflating pressure of each wheel of the aircraft composing the traffic, and finally on probability density function of the lateral distribution of aircraft wheel-path on runway during landing and take-off operations. For this reason, to calculate the number of coverages, it is necessary to know in advance the air traffic volume and spectra operating at the airport, and abovementioned characteristics of each aircraft. Finally it should be necessary to know the lateral distribution of operations. Failing that, it is possible to utilize the lateral distributions of aircraft suggested by FAA [22, 23].

In order to evaluate coverages, a Cartesian coordinate system, where the X axis is coincident with the runaway centerlines, has been used. The number of times that a point of the runway at a distance "δ" from the centerline has been "covered" by the wheels of the j-th gear (i.e. main and nose gears) of i-th aircraft type "$NC_{i,j}(\delta)$", in landing or take-off operation, can be expressed as [19, 20]:

$$NC_{i,j}(\delta) = \left(\sum_{k=1}^{n} V_{i,k} \right)_i \cdot \int_{-\infty}^{+\infty} f_i(y) \cdot R_{i,j}(y,\delta) dy \tag{1}$$

where:

$R_{i,j}(y, \delta)$ number of wheels belonging, to the j-th gear of the i-th aircraft type that cover a point of the runway at a distance "δ" from the centerline, meanwhile the aircraft axis is moving at a distance y from the center line (in a take-off or landing operation);

$f_{i\text{-}landing}(y)$ is probability density function of the lateral distribution of landing (or take-off) paths of the i-th aircraft;

$V_{i,k}$ is the number of departures (take-off) or arrives (landings) of the i-th aircraft type during the k-th year;

n is the number of years to which coverages are referred.

Once that the number of coverages has been evaluated, the number of equivalent coverages (ECs) taking into account a specific damage equivalency criterion, can be therefore evaluated as follows:

$$ECs = \sum_i \sum_j \left(NC_{landing\_i,j}(\delta) \cdot DR_{landing\_i,j} + NC_{take-off\_i,j}(\delta) \cdot DR_{take-off\_i,j} \right) \tag{2}$$

where:

$DR_{landing/take\text{-}off\_i,j}$ represents the relative damage induced in the landing or take-off phase by the j-th gear of the i-th aircraft type compared to that induced by a reference gear according to the specific damage equivalency criterion that has been employed in order to evaluate the friction or roughness deterioration.

In this paper, as previously described, the different damages produced by several aircraft types and gears are evaluated by means of the dissipated frictional energy approach, so the $DR_{landing/take\text{-}off\_i,j}$ is evaluated as [19, 21]:

$$DR_{landing/take-off\_i,j} = \frac{N_{landing/take-off\_i,j} \cdot r_{landing/take-off\_i,j}}{N_{ref} \cdot r_{ref}} \tag{3}$$

where:

$N_{landing/take\text{-}off\_i,j}$ is the normal load transmitted by the j-type landing gear tire of the i-th aircraft type during landing or take-off phase;

$r_{landing/take\text{-}off\_i,j}$ is the radius of tire footprint of the j-type landing gear tire of the i-th aircraft type during landing or take-off phase;

N_{ref} is the normal load transmitted by the reference landing gear tire;

r_{ref} is the radius of tire footprint of the reference landing gear tire.

2.4. Regression Models

As far as the friction deterioration model is concerned, statistical regression analysis can be carried out in order to obtain relationships between IFI (dependent variable) and the number of equivalent coverages (ECs) (independent variable), obtained by using dissipated energy-based damage criterion. The shift exponential model, already proposed in previous works [19, 20, 21], is expressed as:

$$IFI(ECs) = a \cdot e^{-b \cdot ECs} + c \tag{4}$$

where:

a, b and c	regression parameters to be evaluated (c is the terminal IFI value)
ECs	number of equivalent coverages
IFI	friction descriptor, has been chosen within the proposed methodology since it has proven to be effective in describing the skid resistance decay as a function of cumulated traffic.

Evolution of unevenness increases with number of coverages. Particularly, it starts from an initial value (for new pavements), to a maximum value (corrective actions to restore surface smoothness should be taken). For a new pavement initial value of IRI should be between 0.4 (RMSVA= 0.14 mm/m^2) and 2 m/km (RMSVA=1.4 mm/m^2) [10, 24].

A regression model, that seems to correctly represent this phenomenon, is the following:

$$RMSVA(ECs) = a + b \cdot ECs^{c} \tag{5}$$

where:

a, b and c	regression parameters to be evaluated (a is initial RMSVA value)
ECs	coverages
RMSVA	predicted value of unevenness.

It is worth to be highlighted that ECs evaluated for the roughness deterioration model are different from those calculated for the friction deterioration model since these formers are based on a different damage equivalency criterion.

3. Application of the Proposed Modeling Approach to a Case Study

An initial experimental campaign has been performed on the runway of Rome G.B. Pastine Airport. The tests were carried out in three days, moving from 15 to 33 heading, that is the direction almost exclusively used for operations.

The friction tests were carried out by using the French device Adhèra, which is designed to measure the Longitudinal Friction Coefficient (LFC) with a slip ratio of 100%. This device took part to most important experiments about harmonization [8, 25], even if it was seldom used in airport environment.

The tests were carried out over 18 alignments at speed of 60 km/h and an experimental test procedure was used instead of the normalized one (i.e. French standard P 98-220-2 or European standard UNI CEN/TS 13036-2), in order to increase spatial frequency from 10 to 50 tests/km. As the PIARC model [22, 25] requires the knowledge of surface texture, the Mean Profile Depth (MPD) values were measured by a laser device (sampling rate 64 kHz, vertical resolution 0.01 mm).

Runway profile measurements have been carried out through a high performance laser profilometer that is mounted on the front side of the same instrumented van dragging the skid trailer; the equipment is composed of 6 inertial laser sensors (an additional one is devoted to macro-texture evaluation), mounted on a 150 cm long bar [19].

Twelve tests (sweep) were run, by using the above mentioned laser profilometer, along several transversally spaced strips (Table 1). Therefore an overall amount of 72 (= 12 × 6) longitudinal profile alignments, of variable length (between 1750 and 1850 m), have been acquired with a sampling interval of 0.10 m.

The Dichotomic method has been applied to friction and roughness data in order to detect homogeneous section according to the aforementioned procedure. Four zones have been identified following this analysis.

Airport traffic volumes and spectra for several years (from 1994 to 2006) for the Ciampino Airport have been collected. As suggested by FAA, the lateral distributions of aircraft could be rather well represented by normal distribution. In this case study, average and standard deviation of aircraft lateral distribution have been derived from literature [22, 23]. Basing on these data and by making use of the expressions previously, it is possible to derive the distribution of equivalent coverages versus transversal runway position.

As far as the damage equivalency criterion is concerned, a tyre of the main landing gear of the Boeing 737-800 has been assumed as reference tyre in the evaluation of the relative damage.

Table 1. Regression model statistics

Friction deterioration model: $IFI\ (ECs) = a \cdot \exp(-b \cdot ECs) + c$

Zone	Description	Distance from touch down marking of beginning and end of zone	Distance from touch down marking of beginning and end of CCS	*a*	*b*	*c*	R^2	SSR
1	touchdown	From 0 m to 300 m	From 105 m to 145 m	0.358	4.84E-07	0.259	0.78	0.071
2	aircraft deceleration by ground spoiler and thrust reversers	From 300 m to 1200 m	From 985 m to 1025 m	0.422	5.91E-07	0.234	0.96	0.015
3	aircraft deceleration by wheel brakes	From 1200 m to 1500 m	From 1385 m to 1465 m	0.334	1.48E-06	0.276	0.86	0.069
4	approach to exit	From 1500 m to 1750 m	From 1585 m to 1700 m	0.188	5.09E-07	0.377	0.86	0.011

Roughness deterioration model: $RMSVA\ (ECs) = a + b \cdot (ECs)^c$

Zone	Initial Station [m]	Final Station [m]	*a*	*b*	*c*	R^2	SSR
1	0	480	1.2	0.001488	0.390061	0.66	1.76
2	480	820	1.2	1.20E-06	0.935396	0.86	2.31
3	820	1120	1.2	1.33E-06	0.886155	0.78	1.9
4	1120	1620	1.2	0.024646	0.204506	0.59	1.74

In the Figure 1 the *ECs* and the *RMSVA* values are plotted as a function of distance from runway axis for the second zone identified by means of the segmentation algorithm. As it can be observed from the figure the transversal distribution for both are quite similar.

The least squares method was used to fit models to experimental data; the results related to each zone, for IFI and RMSVA, are reported in Table 2, together with the Sum of Square of the Residuals SSR and the coefficient of determination (Pearson's coefficient of regression) R^2.

In this study the starting value of roughness (i.e. construction roughness) has been set equal for all homogeneous sections (i.e. parameter a = 1.2 mm/m^2), as early regression analysis have shown moderate variations. The statistical analysis has showed that friction deterioration models fit the experimental data fairly well. As a matter of fact, minimum correlation coefficient of regression is 0.78 for friction deterioration model and 0.59 for the roughness deterioration model. Furthermore, the model parameters are quite different in the 4 zones, which strengthened the choice of dividing runway length into four zones.

In the Figure 2, the regressions obtained are depicted. As it can be observed, the model matches quite well the measured data. Furthermore, optimal policy for measurement sampling has been investigated in order to reduce the number of data necessary to obtain reliable empirical degradation models. A decreasing number of friction and profile measured alignments has been progressively evaluated, corresponding regression model has been derived and the related Sum of Square Residual, SSR, (i.e. the sum of the square difference between the model estimation and the experimental datum, evaluated on the whole measurement sample) has been calculated. Results are reported in the following table (Table 2).

Table 2. Optimal policy for friction and roughness measurement sampling

FRICTION MEASUREMENTS

Number of alignments	ZONE 1					ZONE 2				
	a	*b*	*c*	SSR	R²	*a*	*b*	*c*	SSR	R²
18	0.358	4.84E-07	0.259	0.071	0.78	0.422	5.91E-07	0.234	0.015	0.96
9	27.26	3.61E-09	-26.66	0.08	0.78	0.38	8.29E-07	0.277	0.017	0.96
7	0.263	9.38E-07	0.38	0.09	0.75	0.527	4.62E-07	0.142	0.021	0.95
8*	2.516	4.51E-06	0.366	50	0.78	0.425	6.51E-07	0.246	0.17	0.95

Number of alignments	ZONE 3					ZONE 4				
	a	*b*	*c*	SSR	R²	*a*	*b*	*c*	SSR	R²
18	0.334	1.48E-06	0.276	0.069	0.86	0.188	5.09E-07	0.377	0.011	0.86
9	0.396	6.61E-07	0.197	0.078	0.84	14.357	4.84E-09	-13.775	0.023	0.96
7	0.337	2.21E-06	0.317	0.093	0.96	8.889	6.59E-09	-8.333	0.018	0.83
8*	0.262	4.64E-07	0.395	8.103	0.94	0.191	6.92E-07	0.395	1.465	0.78

ROUGHNESS MEASUREMENTS

Number of alignments	ZONE 1				ZONE 2				ZONE 3				ZONE 4			
	b	*c*	SSR	R²	*b*	*c*	SSR	R²	*b*	*c*	SSR	R²	*b*	*c*	SSR	R²
72	1.49E-03	0.39	1.76	0.66	1.20E-06	0.94	2.31	0.86	1.33E-06	0.89	1.90	0.78	2.46E-02	0.20	1.74	0.59
36	9.62E-04	0.42	1.76	0.69	1.02E-06	0.95	2.35	0.87	2.53E-06	0.84	1.91	0.76	3.03E-02	0.19	1.75	0.58
24	5.87E-03	0.29	1.82	0.63	4.36E-07	1.00	3.61	0.88	1.33E-03	0.42	2.08	0.67	3.54E-02	0.18	1.76	0.56
18	1.79E-03	0.38	1.76	0.73	3.44E-06	0.87	2.49	0.84	5.06E-06	0.80	1.90	0.77	3.34E-02	0.18	1.75	0.61
15	8.11E-04	0.43	1.76	0.68	1.25E-06	0.94	2.89	0.91	2.05E-06	0.86	1.90	0.79	8.56E-03	0.28	1.84	0.69
12	9.57E-04	0.42	1.79	0.67	3.60E-06	0.86	2.46	0.83	2.42E-07	1.00	1.95	0.85	7.38E-03	0.29	1.91	0.62
11	2.44E-03	0.36	1.81	0.73	3.78E-17	2.52	9.86	0.49	8.44E-07	0.91	1.93	0.76	2.17E-02	0.22	1.86	0.66
9	2.53E-04	0.51	1.80	0.64	1.82E-05	0.75	2.41	0.93	6.58E-05	0.62	1.94	0.80	1.77E-01	0.04	1.76	0.62
8	1.91E-02	0.22	2.01	0.76	6.12E-07	0.98	2.71	0.88	4.19E-03	0.34	2.23	0.50	1.35E-02	0.25	1.79	0.51
7	6.74E-06	0.76	2.10	0.70	4.17E-08	1.16	2.54	0.84	3.26E-12	1.74	2.36	0.82	7.15E-08	1.07	3.50	0.80
6	2.86E-04	0.51	1.86	0.66	8.22E-07	0.96	2.29	0.96	2.22E-06	0.85	1.90	0.95	6.22E-07	0.93	3.59	0.89

[* in this case 8 alignments are within the spacing (-7m, 7m) from the centerline]

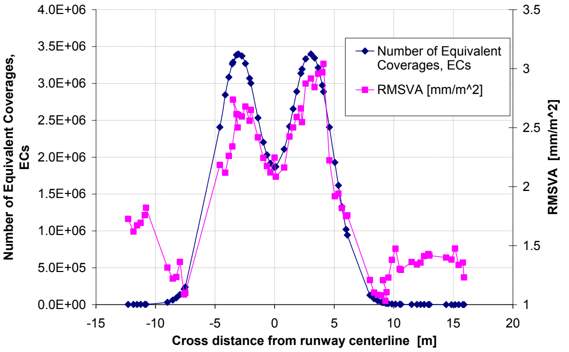
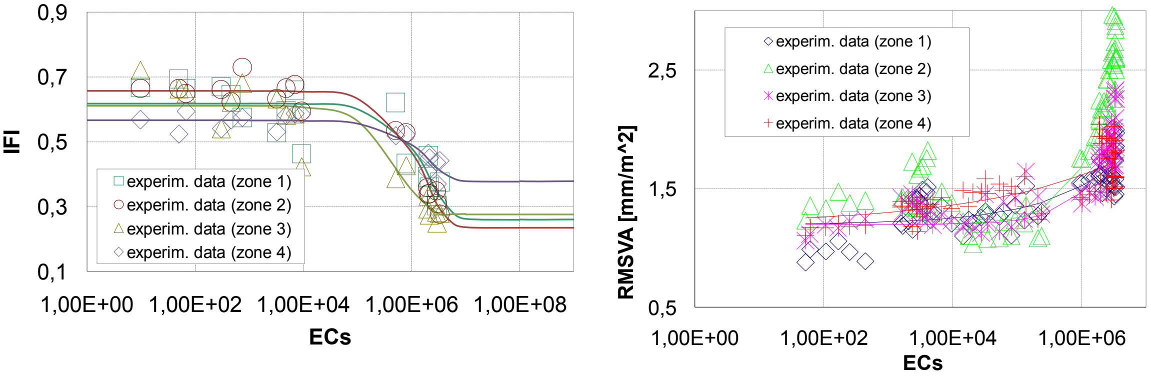


Fig.1. Comparison between the ECs and the RMSVA transversal distribution for zone 2

As it can be observed, as far as roughness measurements are concerned, preliminary results seem to indicate that the approach may represent a viable tool in evaluating the roughness progression even if a reduced sample size of 24 roughness alignment is employed.

Also as far as friction measurements are concerned, satisfactory results are obtained. In fact, even if the sample size is reduced to only 7 alignments, the values of SSR in each zone are quite close to those obtained with 18 alignments. It is suitable to observe that, in order to obtain better friction deterioration models, the alignments should be chosen not only around the probably wheel paths, but in the whole cross section, and the number of alignments should not be less than 7, for the shift exponential model.



(a) (b)

Fig. 2. Observed values and regression models (a) for friction and (b) roughness

4. Conclusion

Deterioration models represent a basic element in Airport Pavement Management Systems (APMS), but their development requires a long time, being based on historical data analysis. The development of preliminary deterioration models could be very useful in order to carry out multi-year analysis in the startup phases.

A new methodology to develop deterioration models of runway roughness and friction has been proposed in order to statistically improve the estimate of model parameters (reduce bias), and to introduce independent variables that capture exhaustively the gear/pavement interaction.

As a matter of fact, the number of equivalent coverages (ECs) has been used to represent the damage induced by traffic in the pavement. Coupling the traffic description by ECs with an exhaustive representation of RMSVA or IFI distribution over runway surface cross-section, a very large data sample can be obtained, even though only one test session has been carried out. Therefore the new methodology proposed is useful to develop more reliable roughness deterioration model, particularly at the beginning of runway flexible pavement life.

The methodology proposed was applied to the analysis of surface friction and profile measurements carried out at the runway of Rome G.B. Pastine Airport, in order to develop the deterioration models of the skid-resistance, in terms of IFI and of roughness in terms of index RMSVA. The models derived from the new methodology and the statistical regressions fit fairly well the experimental friction and roughness data, and the independent variable equivalent coverages "ECs" seems to effectively represent the actions of different aircraft types.

However, it has to be observed that the authors didn't consider the pavement structure to develop the friction and roughness deterioration models. Therefore these models have to be recalibrated before being applied on different airport runway.

Finally, optimal policy for measurement sampling has been investigated in order to reduce the number of data necessary to obtain reliable empirical degradation models. Preliminary results seem to indicate that the approach may represent a viable tool in evaluating the roughness and friction progression even if a reduced sample size of friction and roughness measurements is employed.

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