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Case study

Implementation of a pavement management system for maintenance and rehabilitation of airport surfaces

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ABSTRACT

Airport pavements should satisfy safe and regular aircraft operations; thus, it is necessary to monitor these surfaces and implement expensive maintenance and rehabilitation works. The Airport Pavement Management System (APMS) is an approach to monitor the pavement condition and to determine the priorities for intervention, to plan, and to allocate resources through procedures. The method for monitoring pavement conditions is currently adopted by the airport management company because it is necessary to the airport operability. The study focuses on the paved network of an Italian airport that is composed of a runway, a parallel taxiway and five exit taxiways. Measures of load bearing capacity, transversal and longitudinal evenness, pavement-tire adherence, and pavement distresses were collected and merged to identify the needed maintenance and rehabilitation works. The results revealed the presence of critical sections, where several structural and functional distresses were. The needed structural and functional works involved the greater parts of the runway and the parallel taxiway, and two exit taxiways. Given the high operational impact of the needed works, they were scheduled to be conducted within three phases in order to minimize the impact on the traffic, reducing the closure period to 15 consecutive days. In general, the results summarized approaches typical of different conditions: the article has highlighted that the Pavement Management System (PMS) requires multiple analyses to consider various indices and correctly manage existing pavements having different competences to conduct comprehensive and appropriate analyses.

1. Introduction

In the aviation sector, the need for service quality and safety is increasing in order to offer an efficient transport system [1,2]. A complex system such as the airport needs for routine verification of the compliance with the requirements and rules specified by the national and international competent control authorities. Particularly, the efficient operation of the all facilities is essential to achieve the laid down objectives. Regarding the air side, a pavement management policy permits to receive certification by the national aviation authorities, to ensure the required level of service [3], to reduce the risk of accidents [4–6], and to maximize the benefits deriving from pavement works [7]. Technical and economic problems to deal with are complex. Therefore, management companies define appropriate tools in order to draw up maintenance programs.

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The Airport Pavement Management System (APMS) is the tool implemented to manage airport pavements. It is a decision support system related to technically and economically sustainable management strategies for maintaining the optimal conditions of the airport pavements in compliance with the provisions of current legislations and for a defined period. The system is composed of objective and systematic procedures: inventory of the existing pavements (i.e. collection and retention of geometrical, technical, and mechanical data); monitoring of their performance, planning and scheduling maintenance and rehabilitation activities; evaluation of effectiveness and costs of maintenance activities to be performed as well as those carried out in the past.

In this context, two management levels are usually identified [8]:

- ◦ network level: the overall network of pavements (e.g. all the pavements of the examined airport, or pavements of several airports) is considered, and the main objectives are:
- assessment of the current conditions by mean specific indexes;
- prediction of the short-term and long-term conditions using mathematical methods;
- identification of elements requiring maintenance and/or rehabilitation;
- project level: a specific pavement section, among those identified in the network management as in need of interventions, is considered and the decision concerns:
- technical-economic comparison between maintenance or rehabilitation interventions (e.g. cost/benefit analysis) during the service life;
- prioritization of maintenance strategies;
- identification of specific maintenance or rehabilitation works, and their materials and methods.

Therefore, the main benefits of an APMS could be:

- to encourage the creation of a computerized database to organize, store and consult data about pavements;
- to promote the monitoring of pavements and the systematic and objective assessment of the distress level;
- to predict the evolution of degradation, then to identify when the maintenance and rehabilitation interventions will be needed, the service life of maintenance and rehabilitation interventions, the interventions that show a rate of anomalous degradation evolution, the benefit/cost ratio of the works;
- to select and optimize the list of maintenance and rehabilitation works to be implemented in relation to the allocated resources;
- to allow systematic and documentable identification of the intervention needs, supporting the request for financial allocations;
- to allow greater flexibility and adaptability to changes both in financial assets and human resources.

On the other hand, the implementation of an APMS implies costs related to inventory processes, development and maintenance of database, development or purchasing of the management software, data analysis [9].

However, the benefits from APMS are internationally recognized, and APMS procedures are included in the airport manual and contribute to the maintenance of airport certification [10]. Therefore, failure to perform the APMS activities may lead to restriction, suspension and revocation of the airport certificate.

In this study, APMS is implemented for structural and functional maintenance and rehabilitation of the pavement network of an Italian medium airport whose location is not herein disclosed due to privacy reasons. The presented activities of inspection, maintenance and rehabilitation involved the entire existing circulation network. The current performances of the existing pavements derive from various surveys about the structural and functional state having regard to a 20-year service life.

2. Methods

Managing airport infrastructures includes all the measures aimed at conserving and/or re-establishing the operational functions of the various components of the system, as well as all the measures aimed at verifying and evaluating its effective functionality. It is composed of [11]:

- management activity: it includes all interventions needed to maintain an infrastructure to the required operating conditions without modifying its physical characteristics;
- inspection and control activity: it aims to evaluate the operating conditions of each element of the system, through inspections conducted on a sporadic or scheduled basis, with different levels of in-depth analysis. Particularly, inspections are conducted in accordance with a defined plan that identifies infrastructures and plants to be verified and their minimum level of service, and it includes the analysis of the results in terms of safety and operation under the expected traffic loads;
- maintenance and rehabilitation activity: if the management and inspection activities highlight inefficiencies, restoration and adaptation works must be carried out according to the work schedules.

In order to collect and manage data obtained from inspections and measurements on the examined airport, over the years an object/relational database has been created. The stored data about the pavement network were organized in a structure that represents all the managed superstructures. These were divided into the following physical entities [12]:

- Branch: part of the network that performs a specific function (e.g. runway, taxiway, apron: each track constitutes a branch);
- Section: part of a branch that can be considered homogeneous under the maintenance profile (e.g. pavement type, used materials, thickness of layers, traffic), and it is the minimum element on which planning maintenance and rehabilitation works;
- Sample unit: part of the monitored section where the measurements of the deterioration are performed.

A monitoring system of airport pavement's response to traffic would require considering and evaluating numerous physical properties (objective characteristics) and/or state indices (subjective characteristics) over time [13]. However, economic, technical and logistic issues limit their number. To this end, the adopted APMS used some high-performance measuring devices in order to minimize the number of vehicles and personnel in the detection surveys for a reasonable period. The ICAO Airport Services Manual [14] provides these devices and admits visual investigations to detect superficial distresses. In the examined airport, the considered pavement parameters were:

- load bearing capacity in terms of Aircraft Classification Number (ACN) and Pavement Classification Number (PCN) [15] derived from Falling Weight Deflectometer (FWD) measures [16];
- longitudinal surface pavement evenness in terms of International Roughness Index (IRI) [17] and deviation from a 3 m rolling straightedge (RSE) [18,19];
- transversal surface pavement evenness in terms of rutting (RUT) obtained using a Multi-Functional Vehicle to survey the pavement [20];
- skid resistance measured according to [14], the Advisory Circular FAA AC/150-5320-12C [21] and the Circular of the Italian Civil Aviation Authority [22];
- pavement distress in terms of Pavement Condition Index (PCI) [12,23].

Table 1 lists the frequency of pavement inspections in the examined airport (daily movements are in the range 61–180): functional conditions should be inspected at 36–48 month frequency, and bearing capacity at 60-month frequency.

For each parameter listed in Table 1, hereafter are presented the threshold conditions adopted for the different surfaces.

According to [18] and [15], the ACN values were compared to the PCN values [24,25]: non-destructive deflectometer tests were carried out to obtain data about the existing pavements and the subgrade bearing capacity [26]. The back calculation of data obtained from Heavy Weight Deflectometer (HWD) tests allowed the calculation of the elastic moduli and the Poisson's ratio of the existing pavement layers and the subgrade. Given the fleet mix, both a fatigue and rutting analysis has been carried out. The fatigue law proposed by the Asphalt Institute for bitumen-bound materials and the rutting law proposed by Shell for unbound material were considered [27]. The highest single wheel load (SWL) which causes the pavement failure after 10,000 coverages has been identified in order to calculate the PCN value.

According to the airport's manual, the IRI values has been compared to the reference values in Table 2 in order to identify the most critical conditions.

According to [12], the rutting values (RUT) has been compared to the reference values in Table 3 in order to identify the most critical condition.

Laser technology allowed the texture relief according to the standard ISO 13473-3 [28]. Measures taken every 1 mm contributed to the calculation of the Estimated Texture Depth (ETD). This index represents the mean profile depth of the pavement surface when it is compared to a reference plan through the peaks of its three highest particles [29]. Table 4 lists the assumed threshold values of ETD.

Moreover, laser scanning data were used to calculate the Pavement Condition Index (PCI) according to [12]. This index is a synthetic parameter to evaluate both structural and functional performance of a pavement, used not only for airport surfaces but also for roads and sidewalks [30–32]. The rating procedure is based on a numerical scale, from 100 (perfect condition) to 0 (failed pavement), and its rating scale is related to the maintenance and rehabilitation activities according to Table 5.

Pavement distresses were categorized according to [12] in order to calculate PCI of all the paved surfaces.

Table 1
Frequency of pavement inspections.

Surface	Frequency of pavement inspections (months)			
	Relief and verification of macrotexture ETD	Longitudinal and transversal regularity IRI, RUT, RSE	Pavement Condition Index PCI	Bearing capacity PCN
Runway	36	36	36	60
Taxiway	–	48	36	60

Table 2
IRI threshold values.

Activity	IRI (mm/m)		State	Chromatic index
	Runway	Taxiway and exit taxiway		
No action	< 2.0	< 3.0	Regular	
Next inspection 4 months away	2.0 ≤ IRI < 2.5	3.0 ≤ IRI < 3.4	Acceptable	
Rehabilitation within 1 year	2.5 ≤ IRI < 3.0	3.4 ≤ IRI < 3.8	Pre-critical	
Rehabilitation within 6 months	> 3.0	> 3.8	Critical	

Table 3
RUT threshold values.

Activity	RUT (mm) Runway/taxiway	State	Chromatic index
No action	< 12.5	Regular	
Next inspection 4 months away	12.5 ≤ RUT < 25.0	Pre-critical	
Rehabilitation within 12 months	> 25.0	Critical	

Table 4
ETD threshold values.

Activity	ETD (mm) Runway and taxiway	State	Chromatic index
No action	> 0.75	Regular	
Next inspection 4 months away	0.40 < ETD ≤ 0.75	Acceptable	
Rehabilitation within 1 year	0.25 < ETD ≤ 0.40	Pre-critical	
Rehabilitation within 2 months	≤ 0.25	Critical	

Table 5
PCI rating scale.

Activity	PCI (-)	Chromatic index
No action	> 55	
Next inspection 4 months away	40 < PCI ≤ 55	
Rehabilitation within 1 year	25 < PCI ≤ 40	
Rehabilitation within 2 months	≤ 25	

3. Results

The examined airport has a 2,200 m long runway with a 2,350 m x 300 m strip, one parallel taxiway, one rapid exit taxiways, and four exit taxiways. The circulation network allows link to all directions without generating conflict points between traffic flows (Fig. 1). All paved surfaces are asphalt. No groundwater level has been observed below ground level; no significant seismic, hydraulic and geological risks are in the airport boundaries. In the analysis of pavement conditions, all progressives start at the threshold of the runway 09.

In order to implement the APMS, the design traffic volume was 65,000 yearly movements, and the design life service was 20 years. Table 6 lists the traffic composition.

Fig. 2 represents the traffic distribution over the paved airport surfaces (Figure not in scale).

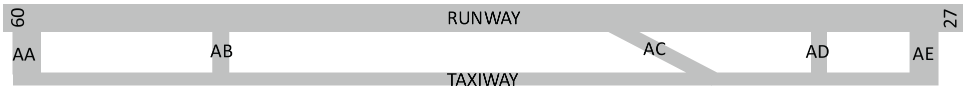

Fig. 1. Map of the examined airport pavements.

Table 6
Traffic composition.

Model	Maximum take-off weight (t)	Maximum landing weight (t)	Yearly movements (-)
ERJ 145XR	24.2	20.0	16,344
Bae 146–200	45.0	33.3	5,422
B737-800	78.0	65.3	37,990
A320-200	77.0	64.5	3,074
A321-200	89.4	77.8	760
B757-200	116.1	95.3	630
B767-200	143.8	123.4	780

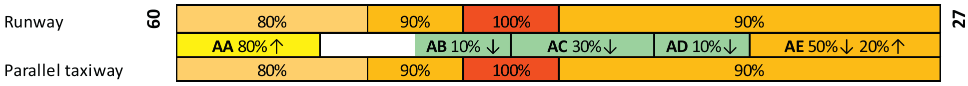

Fig. 2. Traffic distribution over the airport pavements.

3.1. ACN/PCN results

The method ACN/PCN has been applied having regard to the design traffic listed in Table 6. Particularly, the non-destructive deflectometer tests were collected:

- for the runway and the parallel taxiway, at 3 m and 6 m to the left and at 3 m and 6 m to the right of the centerline;
- for each exit taxiway, at 3 m and 6 m to the left and at 3 m and 6 m to the right of the centerline.

The implementation of the ACN/PCN system of rating airport pavements gave the results in Table 7.

The most critical alignments are at 3 m to the left and right of both the runway and the taxiway. Unloaded alignments (e.g. 6 m to the left and right of both the runway and the taxiway) do not reveal critical conditions. However, the sample size in terms of the number of ACN/PCN allowed a statistical approach to interpret the results. According to [33], the reference PCN

Table 7
ACN/PCN results.

Surface	Alignment	Total number of measurements	Number of measurements where ACN > PCN
Runway	6 m left	36	0
	3 m left	72	15
	3 m right	72	15
	6 m right	36	0
Taxiway	6 m left	34	0
	3 m left	34	4
	3 m right	34	8
	6 m right	34	1
AA exit taxiway	3; 6 m left	3; 3	0; 0
	3; 6 m right	3; 3	0; 1
AB exit taxiway	3; 6 m left	2; 3	0; 0
	3; 6 m right	2; 3	0; 0
AC exit taxiway	3; 6 m left	2; 3	0; 0
	3; 6 m right	2; 3	0; 0
AD exit taxiway	3; 6 m left	2; 3	0; 0
	3; 6 m right	2; 3	0; 0
AE exit taxiway	3; 6 m left	3; 3	2; 2
	3; 6 m right	3; 2	2; 2

derived from the 15th percentile of the subgrade bearing capacity in order to avoid considering as representative a PCN value that reflects localized structural deficiencies.

In consequence of this statistical analysis, the most critical conditions are obtained for taxiway whose representative PCN and ACN are 48 and 50, respectively, and for AE whose PCN << ACN.

3.2. Evenness

A multifunctional vehicle permitted to relief the pavement profile and to scan its surface. The post processing of the data allowed calculating the International Roughness Index, the deviation from a 3 m straightedge, the rutting depth, and the pavement macrotexture.

IRI has been calculated for 11 alignments along the runway, 6 alignments along the taxiway, 14 alignments along both A-A and A-E exit taxiways, 6 alignments along A-B, A-C, and A-D exit taxiways (Table 8).

The chromatic analysis highlights the severe conditions of AC (17% of the IRI values are more than 3.8 mm/m); the parallel taxiway, AA and AD have acceptable values of IRI (5%, 7%, and 34% of the total values, respectively), the exit taxiway AE has the best performances. The analysis of the graphical results allowed identification of the pre-critical and critical sections. Fig. 3 shows the results obtained for 6 alignments along the taxiway. Given the obtained curves, it is possible to identify the most severe conditions that coincide with the most trafficked sections according to Fig. 3.

The IRI curves in Fig. 3 demonstrate that the most severe conditions are on the central strips of the parallel taxiway (i.e. at 3 and 6 m at the centreline), where the landing gears load the pavement.

The profilographes obtained from MFV allowed deduction of the Straightedge Index [34] to measure evenness of the runway. This parameter has been calculated at 3 m and 6 m to the left and at 3 m and 6 m to the right of its centreline. Fig. 4 and Fig. 5 show the curves of the Straightedge Index at the left of the runway.

The most critical sections on the left side of the runway (i.e. 240 m, 720 m, and 1550 m) comply with those identified on the right side and coincide with the exit taxiways AB, AC, and AD, respectively.

As regard as the transversal evenness of the pavements RUT has been calculated at intervals of 10 m along the length of both the runway and the parallel taxiway. Four alignments (at 3 m and 6 m to the left and at 3 m and 6 m to the right of its centreline) were examined (Table 9).

Table 9 shows that all the sections (99–100%) are in good conditions, but the results required deepen analyses. Indeed, the curves of RUT revealed acceptable results for the runway sections between 800 m and 1,000 m (Fig. 6) and pre-critical values for the central strips of the parallel taxiway between 700 and 1,000 m (Fig. 7); yellow classes of RUT are on the right side of the taxiway (e.g. 125 m, 420 m, and 1,300 m).

Table 8
IRI results.

Chromatic class of IRI	Frequency of chromatic classes of IRI (%)						
	Runway	Parallel Taxiway	AA	AB	AC	AD	AE
(green)	99	89	86	100	83	66	100
(yellow)	1	5	7	0	0	34	0
(orange)	0	1	7	0	0	0	0
(red)	0	5	0	0	17	0	0

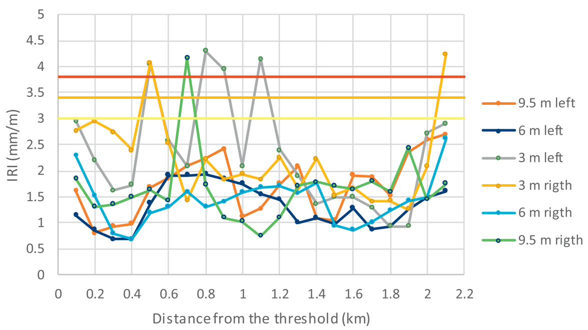

Fig. 3. IRI curves along the parallel taxiway.

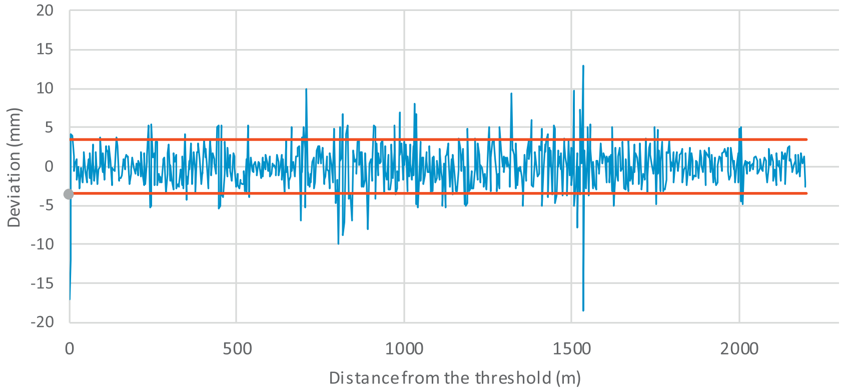

Fig. 4. Straightedge Index curves along the runway at 3 m to the left.

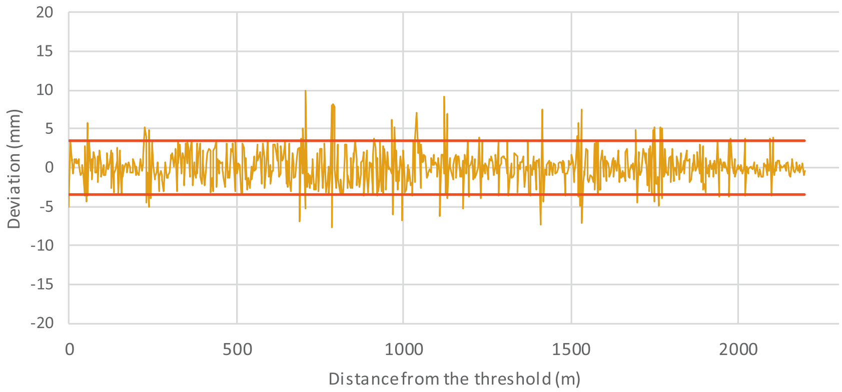

Fig. 5. Straightedge Index curves along the runway at 6 m to the left.

Table 9
RUT results.

Chromatic class of RUT	Frequency of chromatic classes of RUT (%) Runway	Parallel Taxiway	AA	AB	AC	AD	AE
(green)	100	99	100	100	100	100	100
(yellow)	0	1	0	0	0	0	0
(red)	0	0	0	0	0	0	0

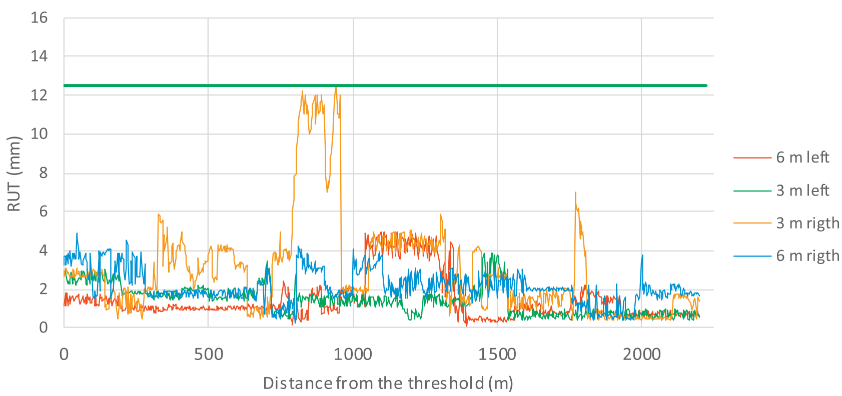

Fig. 6. RUT curves along the runway.

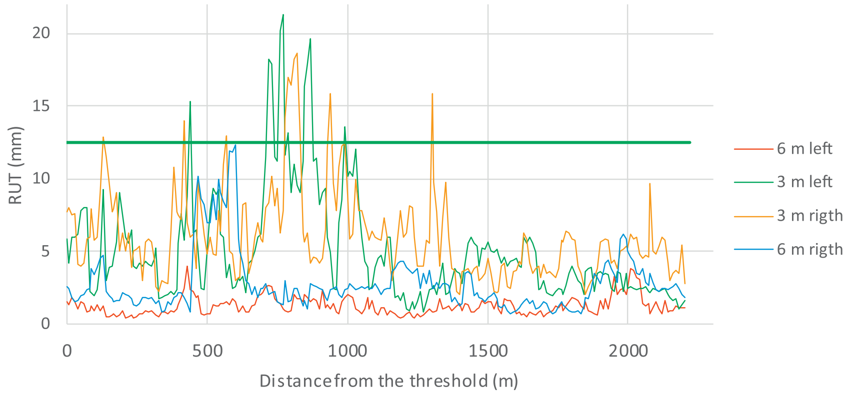

Fig. 7. RUT curves along the parallel taxiway.

3.3. Skid resistance

The ETD values have been calculated along four alignments (i.e. at 3 m and 6 m to the left and at 3 m and 6 m to the right of the centreline) of both runway and taxiway. This choice complies with the need to investigate the keel section of the infrastructures, where landing gears' wheels run, and the highest performances are required. Table 10 summarizes the ETD results.

The curves of ETD reveal the most critical sections of both pavements (Fig. 8 and Fig. 9).

3.4. Pavement condition index

Laser scanning cameras acquired information about the general conditions of the pavements. Each capture gave the geometric coordinates of 4,096 points on a 4 m-wide section: therefore, it was possible to detect the presence of deterioration on the pavement, and to associate some information such as length, severity level depending on the opening

Table 10
ETD results.

Chromatic class of ETD	Frequency of chromatic classes of ETD (%)	
	Runway	Parallel taxiway
(green)	95	88
(yellow)	5	12
(orange)	0	0
(red)	0	0

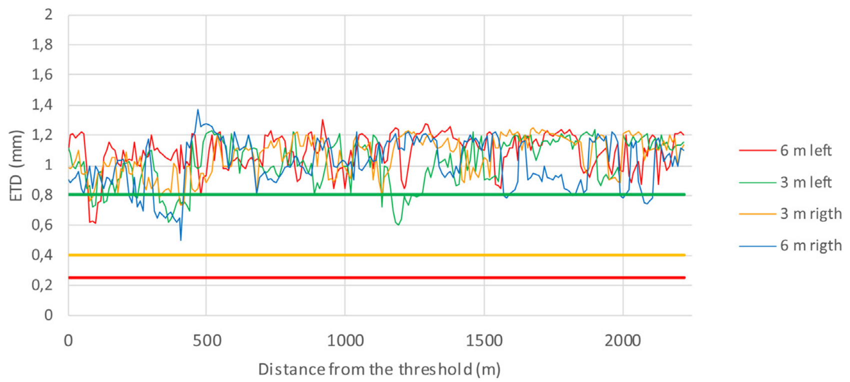

Fig. 8. ETD curves along the runway.

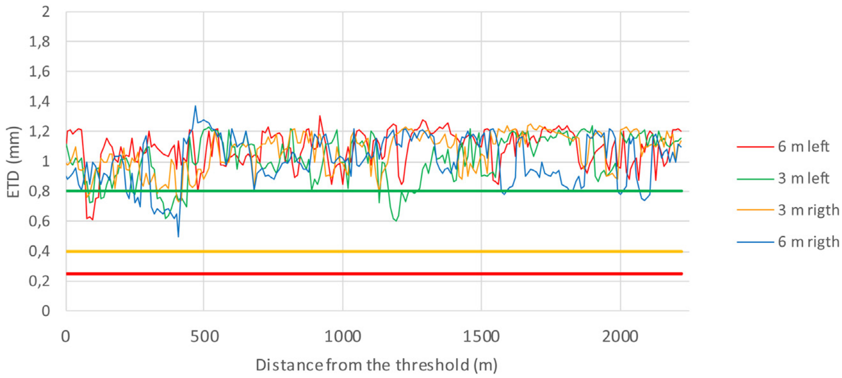

Fig. 9. ETD curves along the parallel taxiway.

width of the slot and the GPS coordinate. Simultaneously with the geometrical survey, high-resolution images were acquired to superimpose the result of the numerical analysis on the visual one.

PCI has been calculated for 6 alignments along the runway, 4 alignments along the parallel taxiway and each exit taxiway. Table 11 lists the frequency distribution of chromatic classes of PCI.

Fig. 10 and Fig. 11 show the obtained PCI curves of the runway and the taxiway, respectively.

The results of PCI calculation revealed high values of PCI in the progressives 0–700 m of the runway, while in its central part (i.e. between 700 and 1,500 m) the index achieves pre-critical and critical threshold values. In the final part of the runway, the most critical sections are at progressives 1,750-1,850 m. The lower values of PCI have obtained for the right side of the runway (i.e. at more than 7.5 m of the centreline).

The curve of PCI calculated for the taxiway (Fig. 11) shows critical and severe conditions for the external areas of the taxiway (i.e. at more than 7.5 m to the right and to the left of the centreline), except for progressives 0–400 m. The most frequently observed distresses were block cracking, alligator cracking, longitudinal and transverse cracking.

4. Discussion

Given all the obtained results, the need for a structural and functional requalification of different areas resulted, and the works were consequently designed in order to guarantee at least a 20 year-service life:

- for the runway a significant deterioration of the physical-mechanical properties of the pavement in the progressives between 0,00 and 240 m, 720 and 1,560 m, 1,740 and 2,200 m has emerged;
- the taxiway showed a clear deterioration of the physical-mechanical properties of the pavement in the progressives between 0,00 and 470 m, and 720 and 1,500 m;
- for the AA exit taxiway, localized areas that exhibit low bearing capacity were identified;
- the AE exit taxiway also required a deepen intervention;
- the AC and AD exit taxiways revealed the need of maintenance to restore their superficial characteristics.

Therefore, the interventions were structural for the runway, the taxiway, and the exit taxiways AA and AE (red areas in Fig. 12), while superficial works to restore functional performances of the pavements were designed for AC and AD exit taxiways (yellow areas in Fig. 12).

Given the high operational impact of the needed works, the opportunity to concentrate them in a single period was evaluated. Therefore, the works were conducted within three phases:

Table 11
PCI results.

Chromatic class of PCI	Frequency of chromatic classes of PCI (%) Runway	Parallel Taxiway	AA	AB	AC	AD	AE
(green)	84	61	99	90	91	89	100
(yellow)	13	26	1	10	9	11	0
(orange)	3	11	0	0	0	0	0
(red)	0	2	0	0	0	0	0

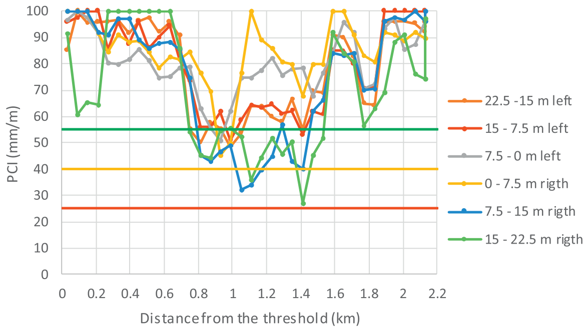

Fig. 10. PCI values along the runway.

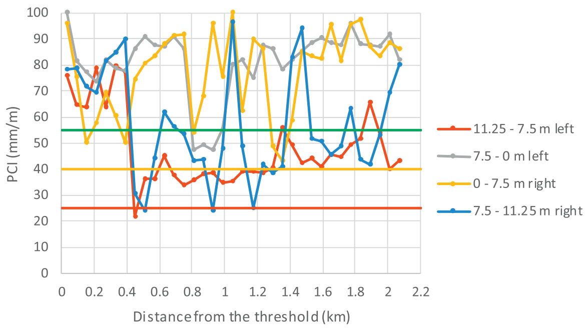

Fig. 11. PCI values along the parallel taxiway.

Fig. 12. Rehabilitated and maintained areas.

- phase 1: under the fully operational airport, all the operations necessary for the construction of the construction sites, the procurement of materials, the assembly and commissioning of the bitumen production plant took place. Granular materials for not bituminous layers were put on a paved non-trafficked area. A polypropylene non-woven fabric sheet was laid on the area in order to constitute a barrier impermeable to percolation water generated by rains. During phase 2, this area was used to accumulate demolition materials: appropriate compartments avoided contamination between different materials. In a different area, the building site components needed to mix the bitumen-bound materials were placed. All storage areas have been equipped with a system for capturing and accumulating meteoric water;
- phase 2: total closure of the airport for 15 natural and consecutive days in order to pave all surfaces. Around 550 people worked on the site, working on several shifts within 24 h and about 300 construction vehicles were used;
- phase 3: under the fully operational airport, all provisional works were demolished, and the original conditions restored.

At the end of the work, the structural and functional performances of the new pavements were measured to verify the effectiveness of the carried out works and to update the inventory PMS data.

5. Conclusions

Efficient airport management needs a considerable amount of technical data about the structure and the state of airport pavements. In the recent years, most of the data are obtained and processed using automated procedures to have accurate and reliable information on the structural and functional performances of the paved surfaces. This process is necessary to improve strategic decisions in PMS: maintenance and repair works should be performed balancing often-conflicting objectives of the best quality, the lowest traffic congestion, and the minimum costs. The paper presents a network level implementation of an APMS: all the paved areas of a medium-size Italian airport were monitored to evaluate their current conditions in terms of bearing capacity, longitudinal and transversal evenness, adherence, and global performance. The results of the reliefs were used to classify the structural and functional conditions (e.g. critical, pre-critical, severe, and moderate) of the examined sections in order to identify the needed maintenance and rehabilitation works. Having regard to a 20 year-service life, both the runway and the taxiways needed rehabilitation works, while the performances of the exit taxiways needed rehabilitation works (i.e. AA and AE) or maintenance works (i.e. AC and AD). More than 100,000 m^2 of the runway and 40,000 m^2 of the parallel taxiway were surfaced during 15 complete and consecutive working days. At this purpose, an ad hoc procedure permitted to supply continuously the required materials during the works and to dismantle work site structures and machines.

Different airport sites could apply the described process in order to implement network level maintenance strategies and to organize maintenance and rehabilitation works.

Conflict of interest

None

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