Conference Paper

Proposal of an Airport Pavement Maintenance Management System for Cape Verde

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Abstract

In order to ensure safe and efficient operation of aircrafts, airport operators are faced with the need to maintain airport runway, taxiway and apron pavements in good condition, within a given budget. In this context, this paper describes the first developments and the methodological approach of a doctoral work with the following objectives: to improve and validate in-vehicle technique for pavement inspection using GNSS, video image capture and Geographic Information System, increasing the degree of automation of pavement distress identification; to develop a procedure for the definition of preventive maintenance strategies for airport pavements, adapted to Cape Verde airport system, using modelling techniques to predict pavement performance and definition of service and trigger levels; and also to develop or calibrate an existing computer application that can be used as a decision support tool.

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1. Introduction

Air transport in Cape Verde is an important catalyst for economic development. Travel between different islands and to the rest of the world justifies the existence of 7 airports that need to be efficiently and sustainably managed especially regarding pavements [1].

To ensure safe and efficient operation of aircrafts, airport operators face the need to maintain airport runway, taxiway and apron pavements in good condition, within a given budget.

Monitoring the evolution of pavements' distresses over time allows to evaluate and predict its quality and develop cost-effective strategies for maintenance and rehabilitation. This is the main goal of Airport Pavement Maintenance Management Systems (APMMS).

The flowchart on Fig. 1 presents the basic components to be considered on the implementation of an APMMS oriented to operate at the network or project level [2-5].

Implementing an APMMS will allow for a sustained management of this assets, supporting management in the process of decision making while prioritizing, quantifying the cost of the activities and developing economically viable strategies for pavement maintenance and rehabilitation. The final goal is to ensure the defined operational conditions during a set time limit [6-7]. Its implementation and maintenance requires investments and time resources to adapt the concept of the system to the reality of one, or a set of airports, within an airport system.
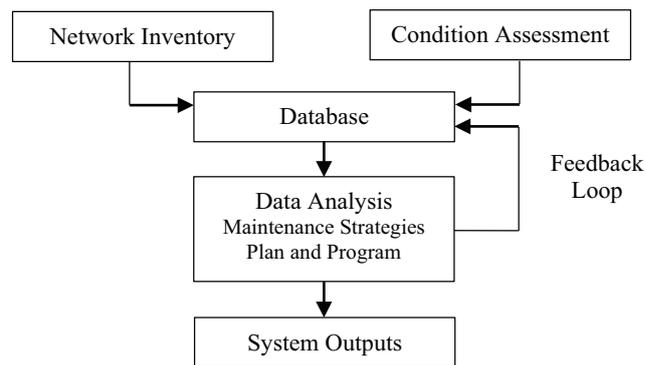

Figure 1: Basic component of APMMS (adapted from [2-5]).

The efficiency of the APMMS depends on the quality of pavement surface and structure condition data. Data must be objective, reliable, up to date and organized by categories, allowing the representation of the behavior of the pavements in every phase of its life [8] to properly evaluate maintenance and rehabilitation needs. Several studies have discussed the definition of APMMS for various situations and using several approaches [5, 9-15] and can be taken into account in defining an APMMS adapted to the reality of Cape Verde.

This research is the starting point of a doctoral thesis that aims to be able to define the basis for an airport pavement maintenance management system for Cape Verde.

2. Approach Proposed for Doctoral Research

The approach proposed for the Doctoral Research is based on the master dissertation entitled Airport Pavement Management System for Cape Verde [3], where APMMS components of inventory and segmentation of the pavement network, in-vehicle pavement inspection and evaluation assessments and computerized database construction, were developed.

Following the previous works, this research intends to increase the degree of reliability and automation of the pavement in-vehicle inspection and data treatment solution and to develop the last phases of the implementation of the APMMS (definition of pavement maintenance and rehabilitation strategies, planning and programming) adapted to Cape Verde airport system, completing the system.

The project aims to contribute to the development of an APMMS adapted to specific realities, in particular with scarce financial and specialized human resources, using recent but low-cost techniques based on established scientific premises and international experience.

To achieve this objective, the following set of specific goals were defined:

Improve the in-vehicle pavement inspection prototype (funding obtained from the II PROTOTRANSFER Competition for Market-Oriented Prototypes) and increase the degree of automation of pavement distress identification.

Test the improved in-vehicle prototype in four international airports of Cape Verde (Amílcar Cabral (AIAC), Praia-Nelson Mandela (AIDP-NM), Cesária Évora (AICE) and Aristides Pereira (AIAP), determination of the Pavement Condition Index (PCI) [16] and validation of the results obtained (statistical analysis).

Develop a procedure for maintenance and rehabilitation needs analysis based in PCI to support the definition of preventive pavement maintenance strategies, adapted to Cape Verde airport system (use of modeling techniques to predict pavement performance, definition of service and trigger levels).

Develop flexible pavement performance prediction models.

Develop or calibrate an existing software application to be used as a tool to support decision making process.

3. APMMS Initial Developments

The first developments of the APMMS are being tested at the international airports of Amílcar Cabral and Aristides Pereira. In the following sections the principles considered in this first phase of the research work and the application to Amílcar Cabral International Airport are presented.

3.1. Pavement network inventory

Establish the pavement network inventory is the basis for the APMMS. Data must be properly organized to be accessible and the collected information should serve a purpose. In this sense, the pavement inspection must be preceded by the preparation and organization of the airport pavements physical, historical and geographic information (segmentation).

In accordance with ASTM D 5340-12 [11] areas of the pavement with different uses (branches) such as runways, taxiways and aprons must be identified and divided in sections and sample units. A minimum number of sample units representing pavements quality for a 95% confidence level must be considered and spacing in-between sample units to be inspected must be calculated. The choice of the first sample unit is random, being the remaining units selected based on the set spacing.

Finally, an alphanumeric code for every branch, section and sample unit must be defined. This code allows an easy identification and information association (collected and produced data).

Fig. 2 shows the segmentation adopted at Amílcar Cabral International Airport. On this airport the 01-19 runway was divided into 3 sections: A, B and C, corresponding to the touch-down areas (extremes) and the central part of the runway. The runway was divided in 9 corridors of 3000m (long) by 5m (wide) to simplify in-vehicle inspection. Sections were divided in sample units with an area of 500m^2 (100m by 5m) [1].
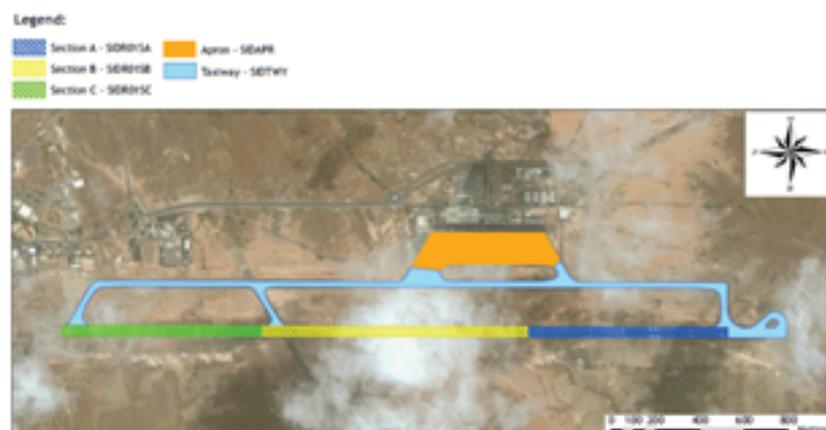

Figure 2: Amílcar Cabral International Airport branches and runway sections segmentation.

After these operations, it is possible to proceed with the pavement surface distress inspection where existing distresses are identified, evaluated (severity level) and measured (areas, length or depth, depending on the distress type).

To validate the proposed in-vehicle inspection procedure, two methods of inspection were applied at Amílcar Cabral International Airport:

1. Traditional visual inspection (on foot)

2. In-vehicle inspection with prototype

The in-vehicle inspection with prototype equipped with laser devices and with the ability to capture and register information on image and georeferencing intends to innovate in the field of pavement evaluation assessments for flexible and rigid airport pavements distress detection. The main goal is to increase the speed and reliability of the collection and identification of pavement condition data. Prototype development was based on early studies and on a previous prototype developed at the Department of Civil Engineering and Architecture of the University of Beira Interiors for road pavement surface inspection [17-19]. The prototype system is composed of a metallic structure to support imaging instrument; a Garmin Elite georeferenced video camera; two 20 mW laser line beams, positioned along and transversely to the survey vehicle's movement direction; two dual band GPS receptors (Trimble 4000SSi); a GPS GIS receptor (Trimble GeoXT); a GPS USB receptor; and one laptop computer.

3.2. Pavement condition assessment

Pavement condition assessment was performed using the Pavement Condition Index (PCI) determination [16]. PCI is a numerical index that quantifies the condition of flexible and rigid pavements, solely based on observation and measurement of surface pavement distresses [20]. PCI scores range from 0 (poor pavement) to 100 (good pavement) and can be interpreted, by the consideration of service and trigger levels, to assess the pavement maintenance needs [21-23]. Fig. 3 present an example of PCI Rating Scale.

Very Good (85-100)
Good (70-85)
Fair (55-70)
Poor (40-55)
Very Poor (25-40)
Serious (10-25)
Failure (0-10)

Figure 3: Example of PCI rating scale (adapted from [16]).

Data obtained from the two inspection methods was used for Amílcar Cabral International Airport sample units, section and runway PCI calculation (Tables 1 to 4).

TABLE 1: PCI values per sample unit in section A.

Code	PCI*	PCI**
SIDR01SA002	36	30
SIDR01SA008	38	40
SIDR01SA014	41	45
SIDR01SA020	43	40
SIDR01SA026	52	52
SIDR01SA032	20	22
SIDR01SA038	52	46
SIDR01SA044	27	30
SIDR01SA050	34	37
SIDR01SA056	46	46
SIDR01SA062	24	26
SIDR01SA068	11	15
SIDR01SA074	60	54
SIDR01SA080	46	48

* Traditional visual inspection (on foot) ** In-vehicle inspection

TABLE 2: PCI values per sample unit in section B.

Code	PCI*	PCI**
SIDR01SB001	22	26
SIDR01SB003	32	26
SIDR01SB009	48	41
SIDR01SB017	25	27
SIDR01SB025	22	28
SIDR01SB033	15	24
SIDR01SB041	17	18
SIDR01SB049	18	16
SIDR01SB057	27	30
SIDR01SB065	56	59
SIDR01SB073	38	38
SIDR01SB081	53	47
SIDR01SB089	31	31
SIDR01SB097	35	29
SIDR01SB105	20	25

* Traditional visual inspection (on foot) ** In-vehicle inspection

3.3. Validation of PCI results

A first overview of the results points to similar PCI results for both assessments. Most of the resulting values are located in the 25 to 40 PCI points interval, meaning that the runway pavement needs interventions in a short time.

TABLE 3: PCI values per sample unit in section C.

Code	PCI*	PCI**
SIDR01SC002	44	47
SIDR01SC008	27	23
SIDR01SC014	32	32
SICR01SC020	36	32
SIDR1SC026	35	29
SIDR01SC032	20	19
SIDR01SC038	35	35
SIDR01SC044	63	53
SIDR01SC050	32	32
SIDR01SC056	43	39
SIDR01SC062	59	54
SIDR01SC068	25	29
SISR01SC074	30	24
SIDR01SC080	26	28
* Traditional visual inspection (on foot) ** In-vehicle inspection		

TABLE 4: PCI values per section and for runway.

Section	PCI*	PCI**
A	38	38
B	30	31
C	36	34
PCI runway	35	34
* Traditional visual inspection (on foot) ** In-vehicle inspection		

For a more meaningful evaluation of the results, the two sets of PCI values were compared statistically for validation of the proposed method. For each set of PCI values, a normality analysis was performed using the Shapiro-Wilk test. The p-values obtained indicate that the two data sets have a normal distribution (p-value > 0.05), so is possible to statistically compare the average (T-Test) and the variance (F-Test) of the two sets. Table 5 presents the main results obtained with the statistical analysis.

TABLE 5: Main statistical analysis results.

Statistical analysis	Traditional visual inspection (on foot)	In-vehicle inspection
N.º of sample units	43	43
PCI Average	34	31
PCI Standard deviation	13,1540	11,3302
Shapiro-Wilk Test (p-value)	0,3401	0,0972
T-Test (p-value)	0,4025	
F-Test(p-value)	0,3372	

From the analysis of the T-test and F-test results, it can be concluded, respectively, that the use of the vehicle equipped does not affect the PCI result (T-test null hypothesis: the average of the two samples is the same and the PCI result is not affected by the inspection being carried out with the equipped vehicle) and that the variance of the two samples is the same (F-test null hypothesis: the variance of the two PCI sets from the on foot inspection and with equipped vehicle is the same). P values lower than 0.05 (95% confidence level for the results) indicate that the difference between sets is significant, otherwise the null hypothesis is accepted.

The results obtained validate the proposed approach (in-vehicle inspection).

3.4. PCI score and the maintenance decision process

The PCI score is used as a pavement quality indicator and therefore used in the decision making related to ensuring a certain level of service. To identify the pavement condition that justifies maintenance and rehabilitation (M&R) actions, a PCI limit named "Critical PCI" is defined [8]. For sections where PCI is higher than the critical value it is considered that the operating conditions are acceptable. Sections with PCI value lower than the critical one generally require maintenance intervention to maintain pavement functional conditions or rehabilitation to ensure user safety.

It is possible to find in the literature several values of critical PCI adopted for the evaluation of runway pavements of international airports [6, 8, 21, 24]. Domingos [22-23] analyzed these values and proposed to the Cape Verde airport system the values presented in Fig. 4. Among the most common preventive maintenance actions it is possible to point out cracks and joins sealing and pavement minor repairs. Pavement milling, reinforcement or surface layer replacement are the most common rehabilitation action. The reconstruction of the pavement involves the removal of existing pavement, correction of the foundation (if necessary) and the construction of a new pavement with new or recycled materials.

Further research to support critical PCI and trigger levels (for specific maintenance or rehabilitation actions) in medium-sized international airports is required and will be undertaken.

Among the most common preventive maintenance actions it is possible to point out cracks and joins sealing and pavement minor repairs. Pavement milling, reinforcement or surface layer replacement are the most common rehabilitation action. The recon-struction of the pavement involves the removal of existing pavement, correction of the

Very Good (85-100)	Preventive Maintenance	Critical PCI (70)
Good (70-85)		
Fair (55-70)	Rehabilitation	
Poor (40-55)		Minimum acceptable PCI (55)
Very Poor (25-40)	Reconstruction	
Serious (10-25)		
Failure (0-10)		

Figure 4: Types of intervention and levels of service on Cape Verde airport pavements (adapted from [23]).

foundation (if necessary) and the construction of a new pavement with new or recycled materials.

Further research to support critical PCI and trigger levels (for specific maintenance or rehabilitation actions) in medium-sized international airports is required and will be undertaken.

Taking into account the critical and minimum acceptable service level defined for the Cape Verde airport system and the results obtained for the runway at Amílcar Cabral International Airport (less than 55), with values close to the border between rehabilitation and reconstruction actions, a site verification to assess the results obtained and the definition of the most appropriate rehabilitation or reconstruction actions should be considered. In view of the results obtained, the airport manager decided to assess the structural capacity of the pavement by conducting Heavy Weight Deflectometer (HWD) tests. The HWD results will be used to determine the Pavement Classification Number (NCP) and consequently to define the best pavement intervention strategy.

4. Conclusions

Pavement data collection and condition assessment are important components of an APMMS that allows to estimate pavement maintenance and rehabilitation needs.

PCI, used to assess the condition of pavements, can also be used to define the type of intervention most appropriated for each pavement situation (preventive maintenance, rehabilitation or reconstruction) and for service levels definition.

The comparison between pavement inspection methods allowed to conclude that the proposed in-vehicle approach has as advantages the possibility of performing the entire pavement's surface condition data collection continuously and at high speeds and the data visualization and analysis in a SIG environment. This allows the information to

be gathered in a shorter span time and the images verification, when necessary, for the same conditions and moment of observation.

The obtained results allowed to validate the in-vehicle inspection method proposed, meaning that this is a valuable resource to support the decision making process related to investments in the pavements of Cape Verde's Civil Aviation System.

Future developments include:

Improvement of the proposed in-vehicle method in order to address the identified difficulties, including the use of a camera with higher image quality and/or the incorporation of a second camera installed in a position that enables a better understanding of the pavement roughness.

Increase the degree of automation of pavement distress identification.

In-vehicle method adaptation for rigid pavement data collection (taxi ways and aprons) and evaluation.

Strategy evaluation component refinement and development of the planning and programming APMMS component.

Acknowledgements

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