Development of Pavement Maintenance Management System For Airports in Egypt

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Abstract: The objective of this research is to assess the condition of general aviation airport pavements in Egypt then develop a systematic maintenance program at their disposal to help airport managers and maintenance personnel in identifying and properly treating the pavement distresses and deterioration. Also assessing the airport pavements will be the main basic for developing pavement maintenance management system for Airports in Egypt. Total runways across the country were surveyed. ***MicroPAVER*** (a PMS system developed by the U.S. Army Corps of Engineers) was selected as the platform for the PMS. An inventory database was developed for all runways in the network. Information about the construction and maintenance history was collected and entered into the ***MicroPAVER*** database. On-site surveys were conducted to assess pavement conditions in terms of the Pavement Condition Index (PCI). Based on the condition survey performed using the MicroPAVER methodology, it was found that approximately 58% of sections surveyed are in "good" to "satisfactory" condition. More importantly, almost 23% of the network can be rated as "good." Also, it was found that 29% of the sections surveyed are in "fair" condition. Overall, the condition of the network can be rated as "satisfactory." A condition curve was developed for each of the two different types of surfaces (Asphalt Concrete AC and Portland Cement Concrete PCC) then the pavement conditions of all branches were predicted. Comparison between two budget scenario reports was developed. The results analysis show that the runways of the general aviation airports eligible for Holding Company funding in Egypt could be brought to a "satisfactory" rating or above (i.e. average ***PCI* ≥ *70***) by spending approximately ***LE 30*** million on average per year for the next ***five*** years. After that, the spending would decrease considerably and the average pavement condition could be kept above ***(70)*** by performing diligent and timely preventive maintenance.

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1. Introduction

Adequate maintenance is always a must for any structure in order to maintain its serviceability and to prevent deterioration that may shorten the service life. In reality, maintenance works are not given the attention it should have as budget approved for maintenance work seldom become prior consideration. However, it is a fact that maintenance is the most important and only activity to be carried out to prolong or at least maintain serviceability of structure until the end of its service life.

Managing a pavement network is a highly complex and complicated task if it is to be taken in its totality. The complexity of the problem derives from the need for reliable pavement performance prediction models and extensive current and historical records of pavement distress, maintenance and rehabilitation history, and traffic loadings of a large number of pavement sections of non-uniform structural properties (Shahin, 1994; Pilson *et al.,* 1999; Ferreira *et al.,* 2002).

Definition of Maintenance:

According to Haas (1978) the definition of maintenance varies among agencies. In a physical sense, maintenance consists of a set of activities directed toward keeping a structure in a serviceable state. For pavement, this includes such work as patching, crack, filling and so on. From Majdi, *et al.,* (2002), definition of pavement maintenance can be described as methods and techniques used to restore or maintain a specified level of service and to prolong pavement life by slowing its deterioration rate.

Function of Maintenance:

Maintenance works are done to achieve desired goals determined during initial stage. There are three main functions in maintaining airport pavements, namely:

- To obtain maximum performance with lowest possible cost.
- Provide safe and sound runway for the safety of aircraft passenger and to achieve rules or regulations set by related organization as (ICAO and FAA); and
- Increases market value and aesthetical value of structure.

Values of Maintenance:

What is the actual value of maintenance? Buildings or any other structures will last longer with proper and continuous maintenance. Poor maintenance may result in the need for reparation, renovation or reconstruction, which will cost more in the end. Maintenance shows its value from the aspect of:

Time:

Compared to time required for reparation and renovation on a structure, maintenance consumes less time, but can produce better quality results.

Cost:

Definitely the costs required by maintenance are lesser then cost required to repair or to rebuild a structure. Furthermore, a specific structure can still be running under maintenance hence saving cost from the economy side of view. Figure 1 shows typical relation between maintenance cost and both pavement conditions and age

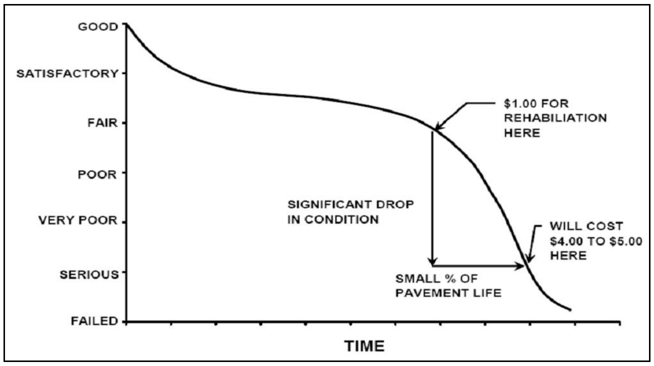

Figure 1: Typical Pavement Condition Life Cycle (Shahin, 1994)

Structure value and performance

Structure will have high value and good performance during its service life if maintenance works are done according to schedule and plan.

Categories of Maintenance

There are two factors that determine types of maintenance to be carried out on a specific structure. First, where will the work be done and second, when will the work be carried out. The maintenance can be classified as the following:

Planned maintenance:

Planned preventive maintenance:

Preventive maintenance has been recognized as a powerful tool to be used along with restoration, rehabilitation and reconstruction. Preventive maintenance is the maintenance carried out at predetermined intervals or corresponding to prescribed criteria and intended to reduce the probability of failure or the performance degradation of an item (BS3811: 1984). Planned preventive maintenance can be further divided into Scheduled maintenance and Condition based maintenance.

Planned corrective maintenance:

Corrective maintenance is the maintenance carried out after a failure has occurred and intended to restore an item to a state in which it can perform its required function. Faulty parts will be replaced or repaired in systematic manner.

Unplanned maintenance: Unplanned maintenance is the maintenance not carried out according to predetermined plan (BS3811: 1984). The main reasons which will lead to unplanned maintenance on a specific structure are sudden failure of structure due to unpredictable situation such as accident, natural disaster Unplanned maintenance are usually carried out by technician or workers in lower rank without seeking further consultation from superior officers because of time constraint.

Maintenance Management:

Maintenance Management is an orderly and systematic approach to planning, organizing, monitoring and evaluating maintenance activities and their costs Abudayyeha et al., 2005). Airport maintenance management involves the following activities:

- Field survey
- Pavement condition rating
- Producing cost-effective maintenance schedule
- Plan maintenance programs and activities
- Control available resources and maintenance activities
- Control cost and expenses on maintenance activities

Aims of Maintenance Management:

Aim of maintenance management is to optimize the use of resources including man power, materials, and equipments in solving maintenance problems. Efficient management is the only key which will lead to good and sound planning. The two actions; Establish maintenance policies and Setup maintenance program have to be carried out to establish an efficient maintenance management:

Summary Related Research:

- A system such as Airport Pavement Management System is a very important tool for pavement monitoring, maintenance planning and budget prediction.
- Visual survey on the pavement surface is part of the Airport Pavement Management System. Measurement index for visual survey is the Pavement Condition Index (PCI) ranging from 0 to 100 guided by Federal Aviation Administration (FAA). Most of the airport analyzes the data been collected by MicroPAVER software.
- Testing such as destructive test is required to evaluate pavement performance.

2. Pavement Maintenance Management Systems (PMMS)

The American Association of State Highway and Transportation Officials (AASHTO, 1985) defines pavement management as "the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the traveling public at the least life cycle cost." This concept of providing pavements and maintaining them in acceptable condition is as old as the first pavement. As a pavement network covers many kilometers of roads, it cannot be effectively managed by simple procedures or experiences of individuals. Instead, a more holistic systems approach is needed. Originally described as "a systems approach to pavement design", the term "pavement management system (PMS)" came into popular use in the late 1960s and early 1970s to describe decision support tools for the entire range of activities involved in providing and maintaining pavements (OECD, 1987). Haas and Hudson (1978) expanded on this by defining "activities" as those actions associated with pavement planning, design, construction, maintenance, evaluation and research.

A pavement maintenance management system (PMMS) provides a consistent objective and systematic procedure for setting priorities and schedules, allocating resources, and budgeting for pavement maintenance and rehabilitation. It can also quantify information and provide specific recommendations for actions required to maintain a pavement network at an acceptable level of service while minimizing the cost of maintenance and rehabilitation. A PMMS is not a "black box" solution but is a tool for helping the engineer, budget director, and management to do a better job in making cost-effective decisions regarding pavement maintenance and rehabilitation (Mudd, 1988). A PMMS typically uses a pavement rating system, called Pavement Condition Index (PCI), as the basis from which current and future pavement condition can be evaluated.

Components of PMMS:

Information must be collected and updated from time to time, decision criteria must be established, alternative strategies must be identified, predictions of the performance and costs of alternative strategies must be made, and optimization procedures that consider the entire pavement life cycle must be developed in order to make full use of a pavement management system (Drenth, and Graff, 2003). A system for accomplishing these objectives must generally include:

- A systematic means for collecting and storing information.
- An objective and repeatable system for evaluating pavement condition.
- Procedures for identifying alternative strategies.
- Procedures for predicting the performance and costs of alternative strategies.
- Procedures for identifying the optimum alternative.

Benefits of PMMS:

The benefits in using a PMMS instead of using engineering experience and judgment alone are as following (Papaleo, 1998):

- Provides a systematic and objective approach to pavement management.
- Allows for multiple budget and maintenance scenarios to be run quickly.
- Provides the pavement engineer with the current pavement condition and an estimate of future pavement condition.
- Provides a database of pavement condition and construction histories.

Maximizes available maintenance funds in a timely and effective manner

Objectives of PMMS:

The major objectives of a Pavement Maintenance Management System are the following:

- Provide the economic and managerial framework for deciding the optimal level of maintenance funding and the optimum level of pavement condition nationwide in both the long-term and short-term perspectives;
- Provide sound methods for developing annual works programmers and determine resource requirements and budgets;
- Allocate funds in a rational and optimized manner to the various maintenance tasks and administrations, particularly under budgetary constrains;
- Schedule and perform the work;
- Monitor the efficiency and effectiveness of the works carried out; and

- Evaluate the consequences of delaying or postponing maintenance on future budget needs and the future deterioration of pavement condition.

3. Determining Maintenance and Rehabilitation Needs

There are four different approaches to estimate maintenance and rehabilitation (M & R) needs which include Ad hoc approach, structured approach, optimum approach and fuzzy logic approach. The first three approaches are well known, time tested, and used by many different agencies (especially the optimum approach). The fuzzy logic approach is relatively new and uses a complex mathematical method to make decisions.

4. Development of a Pavement Deterioration Prediction Model

Pavement deterioration prediction models are an essential component of network-and project-level management. Prediction models are used at the network level for budget optimization by performing life-cycle cost analysis, and to determine data collection needs to assess the present condition of the network. At the project level, prediction models are used to design pavements, perform life-cycle cost analysis, determine the best time to perform maintenance, and select optimal maintenance or rehabilitation measure. The following are the major requirements for any prediction model (Darter, 1980):

- An adequate database
- Inclusion of all significant variables affecting deterioration
- Careful selection of the fundamental form of the model
- Criteria to assess the precision of the model

Deterioration prediction models can classified in two basic classes of models, namely, deterministic and probabilistic. Deterministic models are based on the primary response, structural performance, functional performance, and damage of the pavements in service. Examples of deterministic prediction models include straight line extrapolation, regression analysis, and constrained least squares. Probabilistic models take into account certain uncertainties associated with pavement performance under all traffic and weather conditions. Examples of probabilistic models include survivor curves and Markov models (Lytton, 1987).

Straight Line Extrapolation:

Straight line extrapolation is a simple model based on data gathered during a one-time condition survey. It can be used to develop a pavement deterioration model if a large database with enough pavement condition data is not available. However, if sufficient data is available, a more accurate model should be adopted.

Regression Analysis:

This method relates a dependent variable to one or more independent variables. For pavement prediction models, the measured structural or functional deterioration (dependent variable) can be associated with subgrade strength, axle load applications, pavement layer thickness, and environmental factors (independent variables). This method needs a long-term database and each model is only applicable to specific situations.

Constrained Least Squares:

This model fits polynomial curve to the data that minimize the squared differences between predicted and actual data. Also, this technique applies a constraint that does not allow the curve to have a positive slope. This means that pavement condition is not allowed to increase with age. MicroPAVER, a pavement management system developed by the U.S. Corps of Engineers, uses this method to create prediction models.

Survivor Curve:

Survivor curves use a plot of probability versus time to indicate the percentage of pavement that remains in service at a particular time requiring major maintenance or rehabilitation.

Markov Model:

The Markov model is a special case of dynamic programming. The objective of the model is to choose the actions at the successive points in time in such a way that maximizes the total expected reward over an infinite time horizon. Markov models are used to select a set of actions that will give the biggest reward in the long run or to determine the total reward that can be expected if a certain set of actions are taken. The Markov decision processes can be solved using an algorithm, linear programming, or approximated by standard dynamic programming. The main disadvantage of the Markov models is that it requires a large amount of computations, or a large-scale linear programming software package (Van Nunen, 1976).

5. Research Procedure

Figure 2 shows the research procedures which include the following:

- Select airports of the study, 22 airports in Egypt were studied in this research
- Development of the framework for a PMS
- Generation of an inventory report for the network
- Preparation of a construction and maintenance history report
- Evaluation of pavement conditions of the entire network, Figure 3 shows this task in detail

- Development of deterioration prediction models
- Generation of PCI prediction reports for the next five years
- Generation of network maintenance and repair costs and policies

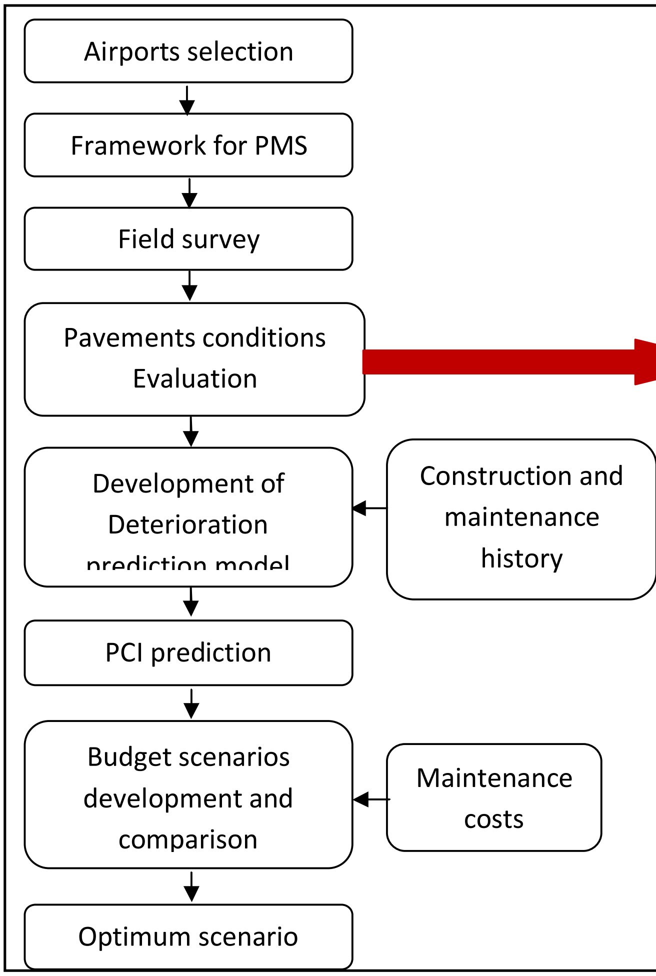

Figure 2: Flowchart of research procedures

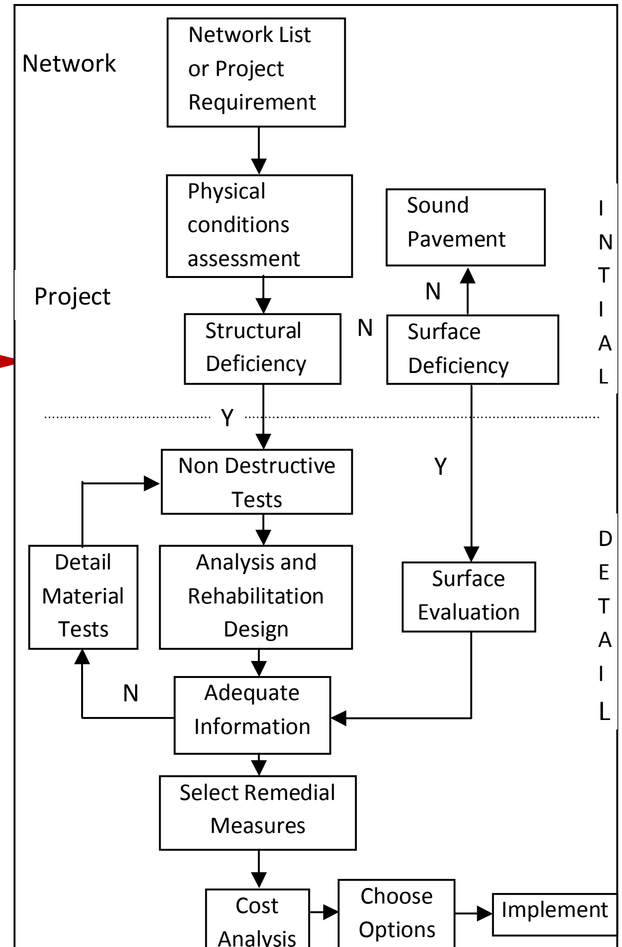

Figure 3: Pavement evaluation process

6. Field Survey and Data Collection

27 runways and 13 Taxiways in 22 airports in Egypt were investigated; Figure 4 shows the studied airports and their classes and Table 1 shows the dimensions of the runways

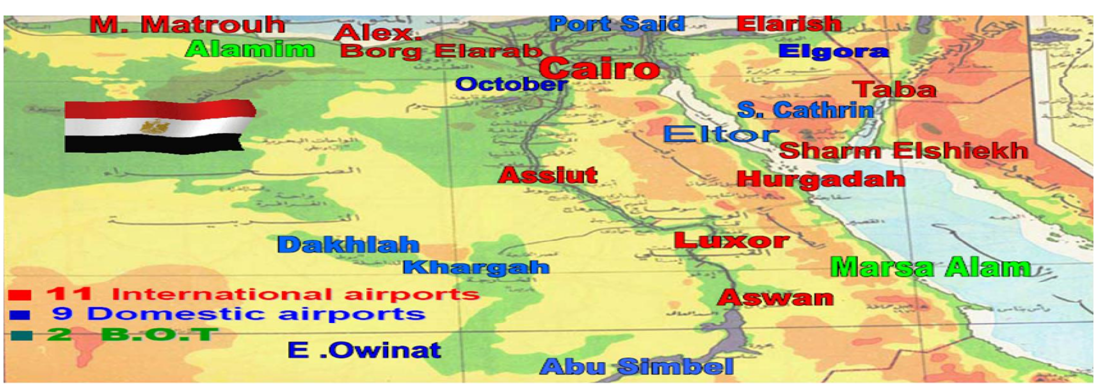

Figure 4: Location of studied Airports

Table 1: Runway Dimensions

No.	Airport name	Runway no.	Length (m)	Width (m)	Shoulder width (m)
1	Cairo Airport	1	3200	45	15
		2	3300	45	15
		3	4000	45	15
2	Luxor Airport	1	3000	45	15
3	Aswan Airport	1	3400	45	15
4	Hurgadah Airport	1	4000	45	15
5	Elnozha Airport	1	2200	45	15
		2	1800	30	7
6	Sharm Elsheikh Airport	1	3080	45	15
		2	3080	45	15
7	Asuit Airport	1	3020	45	15
8	Taba Airport	1	4000	45	15
9	Marsa Matrouh Airp.	1	3000	45	15
10	Borg ELarab Airport	1	3400	45	15
11	ELarish Airport	1	3020	45	15
12	S. Owinat Airport	1	3500	45	15
13	S. Cathrin Airport	1	2115	36	15
14	Abu Simple Airport	1	3000	45	20
		2	3000	45	20
15	Port Said Airport	1	2350	45	15
16	ELtour Airport	1	3000	45	15
17	Dakhlah Airport	1	2490	45	15
18	Khargah Airport	1	3500	45	15
19	Marsa Alam Airport	1	3000	45	15
20	Alamin Airport	1	3500	45	15
21	6^{th} October Airport	1	2000	35	15
22	Algora Airport	1	2400	45	15

Before surveying conditions, the runways were divided into sample units sections, based on the surface and the width of each runway. The dimensions of each unit was 15 m x 40 m at center of pavement as well as 15m x 40 m and 10 m x 60 at edges for pavement with ≥ 45 m width and ≤ 35m respectively. This was done to create sections with an area of approximately 600sq. m and to facilitate the surveying process. About 20% to 30% of the sample units were selected randomly using software to be surveyed.

Portland cement concrete (PCC) runways were divided into sections based on the number of slabs in the width direction. The aim was to create sections of 20 slabs in such a way that would allow a two-man survey crew to constantly walk forward. The 20 slabs ranged from 2 x 10 slabs to 4 x 5 slabs at the center of the pavement based on the number of slabs in the width direction and were 2 x 10 slabs at pavement's edges for all rigid runways.

During summer 2010 the severity and intensity of 16 pavement distress were surveyed for the runways of the 22 airports according the sample size explained above and the ASTM 5340-04 procedure; Table 2 shows the surveyed pavement distresses. Figure 5 shows some other field tests as core works and computer system of runway friction testing vehicle. The core woks were used to determine the layer thickness and materials properties foe some runway where this data cannot be collected from its construction and maintenance history

Table 2: Types of pavement distress

Alligator Cracks	**Block cracking**
Bleeding	**Corrugation**
Depression	**Joint reflection cracks**
Jet blast erosion	**Longitudinal & Transverse cracks**
Oil spillage	**Polished aggregate**
Patching	**Raveling & Weathering**
Rutting	**Slippage Cracks**
Shoving	**Swelling**

7. Analysis and Discussions

Pavement condition summary: Based on the condition survey performed using the MicroPAVER methodology; it was found that approximately 58% of sections surveyed are in “good” to “satisfactory” condition. More importantly, almost 23% of the network can be rated as “good.” Also, it was found that 29% of the sections surveyed are in “fair” condition. Ideally, these sections should receive maintenance as soon as possible to avoid costly maintenance actions in the future. Overall, the network has a PCI of 74, which earns it a “satisfactory” rating. Figures 6 and 7 show the number of sections and percentages within each class of the PCI rating.

Computer system in Runway Friction Testing Vehicle

Coring Work

Figure 5: Some field tests used to investigate the pavement of the studied runways

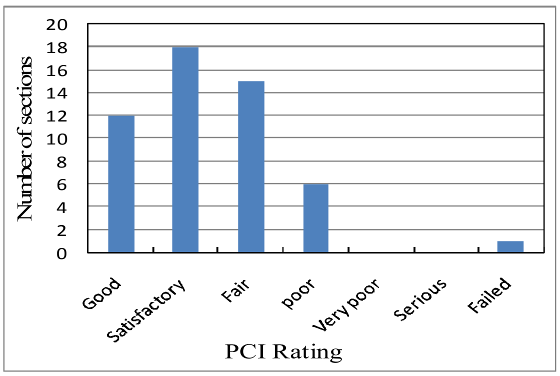

Figure 6: Number of Sections by PCI

Figure 7: Pavement Conditions Summery

Using MicroPAVER's "family method," two condition prediction curves were developed, one for each of the different surface types, asphalt and concrete as shown in Figures 8 and 9. During development of the curves, it was found that the climatic zones in Egypt have no impact on pavement performance of the GA runways.

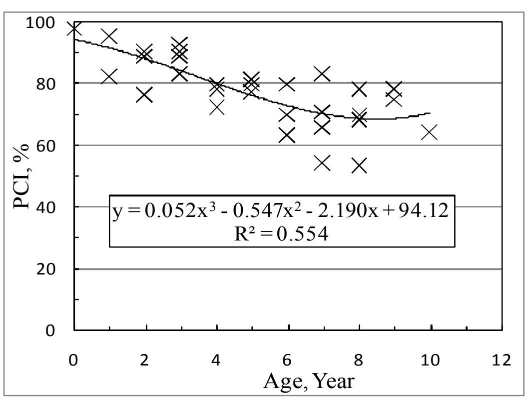

Figure 8: Family Curve for Asphalt pavement

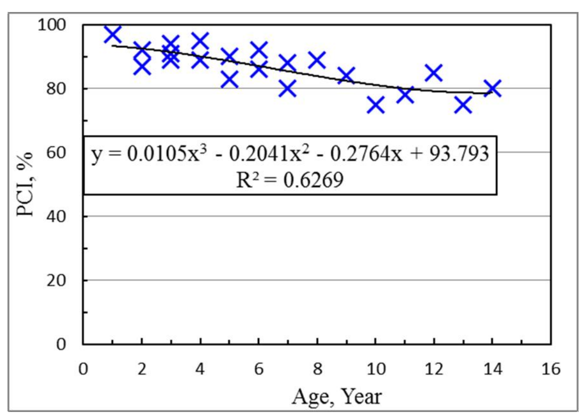

Figure 9: Family Curve for Concrete pavement

As shown in Table 3 and Figure 10, prediction of future condition shows that the number of branches rated "good" could decrease by 42% by end of 2012 if the branches receive no maintenance. Also, as much as 50% of the entire network could have a rating of "fair" by 2015, if the branches only receive routine maintenance.

Table 3: Predicted Pavement Conditions Summery

PCI Rating	Year		
	2010	2012	2015
Good	23.1	13.5	9.6
Satisfactory	34.6	38.5	19.2
Fair	28.8	30.8	50.0
Poor	11.5	13.5	15.4
Very poor	0.0	1.9	3.8
Serious	0.0	0.0	0.0
Failed	1.9	1.9	1.9
Average network rating	**73**	**71**	**66**

Table 4: Suggested Maintenance Actions Based on PCI of Section

PCI Range	Surface Type	
	AC pavement	PCC Pavement
90 - 100	Do nothing	Do nothing
80 - 90	Check repair	Joint sealant and crack repair
70 – 80	Check repair and patching	Joint sealant, crack repair and patching
50 - 70	Check repair and patching or slurry seal or overlay	Extensive patching and joint sealant
30 – 50	Check repair and overlay	Slab replacement or overlay
< 30	Thick overlay or reconstruct	Overlay or reconstruct

Table 4 shows a list of maintenance policies based on current PCI values has been presented.

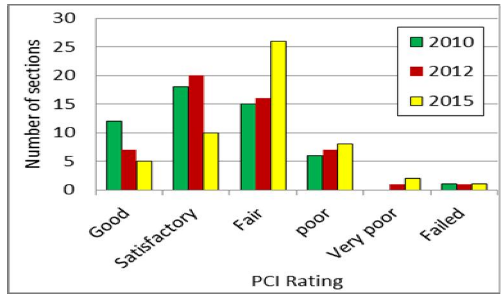

Figure 10: Pavement Condition Prediction Summary

These policies can be used to create a strategic plan to maintain the network PCI at a high level. The maintenance policies served as the basis for the budget forecasting reports

Table 5 shows the budget scenario comparison reports that created based on the outcomes of this research. It shows that some runways of the General Aviation GA airports eligible for Holding Company funding in Egypt could be brought to a "satisfactory" rating or above (i.e. average PCI ≥ 70) by spending approximately LE 30 million on average per year for the next five years. After that, the spending would decrease considerably and the average pavement condition could be kept above 70 by performing diligent and timely preventive maintenance.

Table 5: AC Runways Budget Scenario Comparison

Year	Budget Scenario 1			Budget Scenario 2		
	Min PCI	PCI after treatment	Cost, LE million	Min PCI	PCI after treatment	Cost, LE million
2011	55	77	37.8	30	72	15.6
2012	60	79	49.2	40	71	10.1
2013	70	87	38.4	50	72	15.2
2014	70	87	13.2	60	81	51.8
2015	70	85	10.0	70	90	38.2
Total			148.6			130.9

8. Conclusions

In this study, an inventory database for all GA airports in Egypt was developed. This inventory was used to form the basis for a MicroPAVER-based pavement management system for all GA airports in Egypt. Based on the condition survey performed using the MicroPAVER methodology, it was found that approximately 58% of sections surveyed are in "good" to "satisfactory" condition. More importantly, almost 23% of the network can be rated as "good." Also, it was found that 29% of the sections surveyed are in "fair" condition. Ideally, these sections should receive maintenance as soon as possible to avoid costly maintenance actions in the future. Overall, the network has a PCI of 76, which earns it a "satisfactory" rating.

Using MicroPAVER's "family method," two condition prediction curves were developed, one for each of the different surface types, asphalt and concrete. During development of the curves, it was found that the climatic zones in Egypt have no impact on pavement performance of the GA runways. Prediction of future condition shows that the number of branches rated "good" could decrease by 42% by 2012 if the branches receive no maintenance. Also, as much as 50% of the entire network could have a rating of "fair" by 2015, if the branches only receive routine maintenance.

A list of maintenance policies based on current PCI values has been presented. These policies can be used to create a strategic plan to maintain the network PCI at a high level. The maintenance policies served as the basis for the budget forecasting reports.

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