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An overview of the airport pavement management systems (APMS)

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Abstract

Airport Pavement Management System (APMS) is a useful tool, including a set of procedures for collecting, analyzing, maintaining, and reporting pavement data, thus assisting airports in finding optimum cost-effective treatments to preserve their pavement assets. The paper provides an in-depth overview of the APMS from an extensive literature review with the aim to identify numerous issues within APMS, such as the components, Pavement Condition Indices, software utilization, and the comprehensive implementation process. The methodology adopted for this research is a descriptive-based study approach on the various airport pavement manuals, guidelines and advisory circulars, journal articles, and book publications for the APMS applications. The airport pavement management systems and the case studies in various airports internationally will be included in the review. The study includes various subjects such as major components, benefit and cost approach, management in different levels, software utilization, maintenance, and rehabilitation (M&R) policies in the implementation of the APMS. Additionally, the research examines the pavement performance indicators that are the key elements for evaluating pavement conditions. Besides, the APMS software programs can store historical information, analyze data, develop models, and generate reports for M&R in association with the budget, including estimating future pavement life. The study summarizes the condition data required for the implementation and operation of an APMS, as well as the information generated by the APMS. The review highlights the benefits of an APMS in providing the airport operators and engineers far more informed position for decision-making to forecast future pavement maintenance requirements for an adequate and timely M&R.

Keywords: Airport pavement management system (APMS); Pavement condition indices; Software; Maintenance & Rehabilitation; Guidelines of APMS

1. Introduction

The Airport Pavement Management System (APMS) is the process exercised to supervise airport pavements. It is related to technically and economically sustainable management strategies to maintain the optimal scenarios confronting the existing regulations through systematic decision support procedures [1]. APMS is extensively used for conducting various integrated tasks to maintain long term service of the airport pavement. In this arrangement, the maintenance program is scheduled as per the recommendations, and rehabilitation costs are specified [2]. Traditionally, most of the designated authorities make decisions regarding maintenance and rehabilitation (M&R) based on experience and established appropriate engineering practices and thus manages airport pavements [3].

Nonetheless, this critical asset has developed considerably; thus, many airport agencies started using the Airport Pavement Management System (APMS) to manage this infrastructure since 1985. Broten [4] reported that in the United States, around 84% of state aviation agencies were using APMS. The enactment of Public Law 103-305 in 1995 has changed the situation dramatically. According to the law, an airport agency should have an effective pavement maintenance management system is under operation to become eligible for getting federal funding. The function of an APMS is to develop cost-effective strategies and, thus, direct decision-makers to maintain the pavements functionally over a given period. APMS follows a systematic procedure for determining needs and priorities, planning and schedules for maintenance, and required resource allocation. It delivers specific pavement network maintenance recommendations at an acceptable level of service after analyzing the collected information and optimizing the expenditures [3]. APMS facilitates improving management capabilities and up-level traffic. The majority of airport administration makes decisions for pavement maintenance and rehabilitation program followed by current needs or experience rather than fostering repair through an "ad hoc" basis [2].

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Pavement Management System is a tool that should not be a substitute for engineering judgment by humans. Nonetheless, it can help engineers and airport authorities to make the right decision during project implementation [5]. A budget projection model using the maintenance cost and condition indices relationship can be incorporated in a Pavement Management System(PMS) for benchmarking pavement maintenance among the transport authorities [6].

2. Research objectives

Airport authorities, operators, and other organizations are investing billions of dollars globally for airfield pavement maintenance & rehabilitation and keep it in an acceptable serviceable condition for a certain period. Pavement Management System is inevitable in a constraint budget situation to forecast the pavement maintenance cost, including alternative strategies and set priorities and optimum implementation time.

The objective and the reasons for conducting the study are as follows:

1. Provide a comprehensive outline of the airport pavement management system, including the main components, benefits, costs, and implementation process.
2. Discuss Pavement Management System practices and guidelines followed by different international airports.
3. Identify the available pavement condition indicators that are using to evaluate the overall condition of the pavement.
4. Demonstrate the significance of software program utilization in APMS.

The study would provide a clear understanding of APMS implementation procedures to the concerned airport agencies regarding the appropriate maintenance level for available resources to be executed most effectively on their airfield pavements.

3. Benefits and costs of airport pavement management

3.1. Advantages of APMS

APMS facilitates airport authorities to administer cost-effective decisions related to specific Maintenance and Rehabilitation programs customizing optimum timing and understanding the long-term impacts of those decisions integrated to funding allocation [2,3]. In particular, pavement conditions are improved steadily since the implementation of APMS with proper database fabrication among different U.S. states [4]. APMS has a systematic and documentable engineering basis for determining M&R needs, including consideration of future operational needs for airport expansion projects. It employs a Life cycle cost analysis of M&R and identifying the impact on the pavement and documentation of present and future conditions. Moreover, it can Identify budget requirements & provide optimum M&R plans within the budget. Furthermore, by applying a cost-effective treatment at the proper time, the pavement condition is improved, and this systematic preservation treatment eliminates costly rehabilitation and reconstruction and thus increase the pavement service life [7].

3.2. Costs involved with APMS

The cost required to establish an AMPS is associated with installing computer hardware and relevant software, including expert and labor costs. Afterward, the costs involved are inventory & data collection, analysis of these collected data, pavement condition assessment, launching, and maintaining a database. Some regular maintenance costs are required to keep the database updated for operation and maintenance of the APMS with key personnel. Besides, providing training for both employees and refresher for their professional development also causes additional costs [3].

4. Components in work levels and approaches of APMS

Airports are basically separated into two main areas, which are landside and airside. The airfield pavements consist of the runway(s), taxiways, taxi lanes, and aprons, which are considered in the airside area [8]. Airports airside pavement operation and maintenance program actions of the pavement areas provide benefit and uphold by the data contained in the APMS. PMS mainly works at two stages, which are Network level and Project level. The pavement management can be implemented at the network level as demonstrated in Fig. 1, where needs are determined, overall pavement condition is evaluated, and future state of the network is predicted, and put a priority on the requirements for intervention either in preventive or preservation of specific segments through rehabilitation or reconstruction. Finally, prioritization is formulated through planning and budgeting [9].

4.1. Airport pavement management in network and project level

4.1.1. Network level management

At the Network level, queries related to short-term and long-term budget requirements and the overall pavement network conditions, including present and future, are resolved. The evaluation at the network level helps to set the priority of M&R techniques such as which section requires rehabilitation, reconstruction, or recently maintained and utilizes the optimum funding requirement in the entire pavement network management. The assessment level generally consists of a visual inspection of each pavement section of the network. Local considerations are given for the airport pavements, whereas state consideration includes all the pavements under the state airport system [3].

4.1.2. Project level management

In the project, level management decisions are taken, followed by the most cost-effective M&R alternative for a particular pavement section during network analysis. The assessments are more analyzed and elaborate than the network level. Multiple pavement sections are included in a project, and a detailed survey

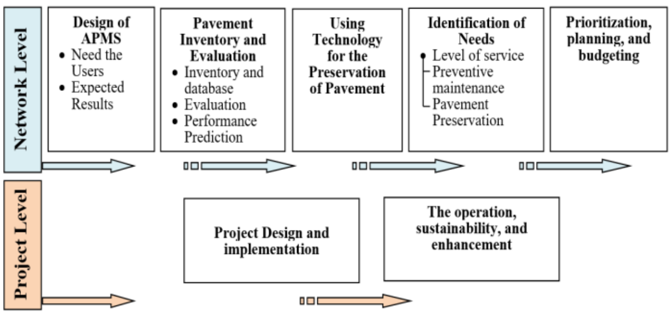

Fig. 1. Components of an APMS in two work levels (Adapted from [9]).

has been implemented for each pavement at this level so that different M&R options can be prescribed for different sections. Generally higher rate of sampling is done during pavement inspection. Besides, additional testing like roughness, friction, or core cutting may be executed for specific purposes. Moreover, some destructive or non-destructive tests may be required to identify the pavement's load caring capacity [3].

4.2. Other management levels

There are two other management levels involved in PMS, which are Administrative levels and Technical management level. Generally, budgets and priorities selected for any program are dictated at the administrative level. Decisions on the best suitable design, maintenance, or rehabilitation techniques and process for an individual project are taken under Technical management levels [5,10].

4.3. Approaches to airport pavement maintenance and rehabilitation in the traditional system:

In the conventional system, most of the airport authorities have taken decisions regarding their pavement maintenance and rehabilitation on the basis of instant requirement or experience rather than long-term M&R planning [5]. Different agencies use several approaches to ascertain the required maintenance and rehabilitation in their USA's airport pavements. There are three common approaches which are briefly discussed below [11]:

One of the approaches is the "ad hoc" approach, which several agencies frequently take. The agency's workforce implements M&R alternatives based on their experience to solve the problems under this approach. The prime limitation of this approach is that the solutions are coming from habitual application from a set of alternatives may not be reflected in the best economical options.

The second approach is termed the "present condition" approach under which several condition indicators first evaluate facilities. These indicators are then analyzed, and an M&R alternative is determined to attend to the circumstance. The significant benefit of this approach is that the given M&R alternative directly treats the deficiencies found in the facility, while the option may not be the most cost-effective one.

The third approach is called the "life-cycle" approach, which requires an in-depth assessment of the facility under consideration and predicting its future condition. This approach is preferable because it ensures the most economical M&R alternative, which is obtained through a life-cycle cost analysis [11].

5. Airport pavement management system implementations

APMS involves a considerable investment of resources with a time constraint for proper implementation. Fig. 2 illustrates the flow chart of APMS implementation.

5.1. Potential users and their requirement

APMS users vary based on the implementing agencies, such as an individual airport, state or regional authorities, or a military branch. Many large airports possess an engineering department that needs detailed and technical information outside of the APMS. Geographic information systems (GIS) based software program is significant for this group's pavement management. A larger

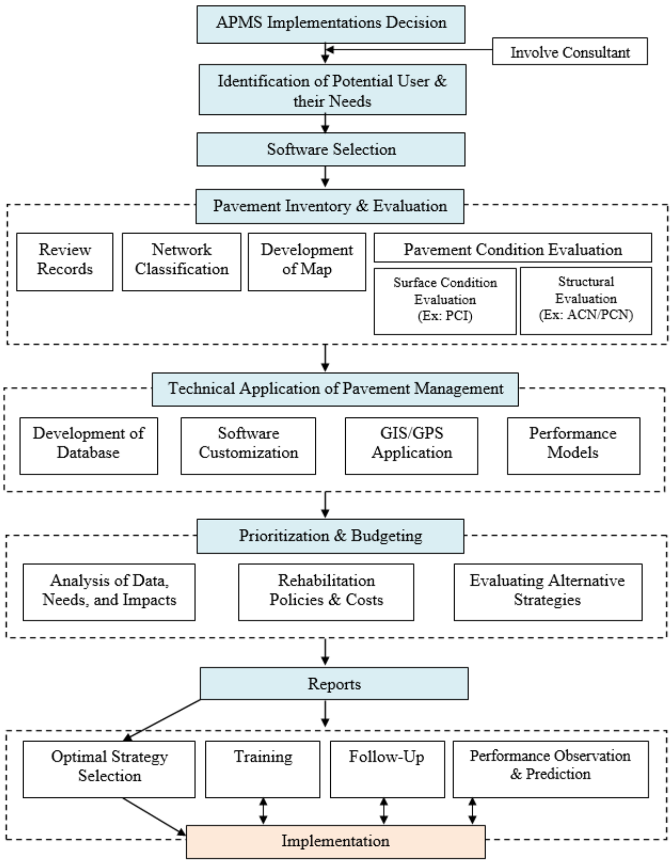

Fig. 2. Flow chart of APMS implementation.

airport comprises a maintenance department that uses the data and information provided by the APMS. Moreover, the finance department is also an integral part of some airports. The operations department and the upper airport management groups do not concern much about the M&R policies and outcomes; instead concentrate on maintaining the pavements open for use, which is the most beneficial for them [3].

5.2. Software selection

The software selection depends on the required type and the available funding to develop or purchase it from a proprietary software company. Apart from the cost and type, some other factors govern the selection of APMS software. One crucial feature is the user interface since some software is easy to operate while some render a graphical interface, GIS links, or other spatial attributes [3].

5.3. Pavement inventory and evaluation

5.3.1. Review of the records

A detailed review of the existing records is conducted to collect successive data to ascertain the APMS analysis. The existing records review includes sufficient construction and maintenance history of each section of the system's pavement. Some other data are collected like information from the past inventory of pavement condition, climate-related information such as precipitation and temperature, and traffic pattern in that designated pavement. There are two significant guidelines demonstrated to determine the scope of past information to incorporate in inventory. Firstly, it should be easily accessible to avoid wasting time searching for records. Secondly, the data should meet the purposes [3].

5.3.2. Network classification

According to FAA AC 150/5380-6A (2003) and ASTM Standard D 5340 (2003), the network classification consists of four main divisions, which are network, branch, section, and sample unit, as depicted in Fig. 3. In an APMS, an individual airport is considered as a network. The network is broken up into a couple of branches. Afterward, the branches are then divided up into smaller segments defined as sections. Each section must contain a consistent design, history of construction, traffic, and condition as per ASTM D5340. The Sections are the critical management units that select prospective Maintenance and Rehabilitation of that project. The Sections are divided into the small part at the final stage in the network definition system, termed units [3].

5.3.3. Development of map

Maps show significant pavement sections, including dimensions, sample units, and quickly identify any specific sample unit that needs assessment. Usually, these maps are generally developed in scale so that it can access easily by the field personnel during conducting the survey and interpolated in the field. These maps are basically produced by utilizing computer-aided design (CAD) software tools. Once a base map is developed, other properties such as lighting, landing systems, and drainage structures are produced layer-wise and expressed accordingly [3].

5.3.4. Evaluation of pavement

Surface condition evaluation

Assessment of pavement surface or functional condition is one of the crucial parts of pavement management. The process of pavement functional condition evaluation depends on skid resistance (safety), roughness (ride quality), surface distress, and potential for foreign object damage (FOD) to aircraft [12,13]. Safety is ensured by maintaining the required surface friction. The evaluation of a pavement's surface condition allows deciding whether the existing pavement is adequate for current services. Moreover, an indication is also obtained for structural evaluation requirements, figure out the reasons for surface distress, and fix maintenance and rehabilitation priorities, including scheduling based on needs [12].

Pavement condition indices

In the early days, pavements performance evaluated whether they were satisfactory or unsatisfactory [14]. In the late 1950s, a much more comprehensive effort was delivered to identify pavement conditions' deterioration. The pavement condition index has been developed, later, combining several indicators of pavement distresses into a single number as an indication of pavement performance [10,14].

Pavement condition index (PCI) Many aviation agencies utilize the pavement condition index (PCI) methodology, which was invented by the U.S. Army Corps of Engineers. The PCI process is demonstrated in FAA AC 150/5380-7B [7] and ASTM Standard D5340 [15]. The PCI values are determined on the basis of visual inspection and identify the types of distress, magnitude, and quantities prevalent on the pavement surface, as illustrated in Fig. 4. It is extensively utilized both in the Highway and Airfield pavement.

PCI indicates the rating of the pavement's condition, and the scores vary from 0 (failed) to 100 (excellent), as shown in Fig. 5. It conveys the condition of the pavement with a constant and serves to express the condition of the pavement in a consistent and explicable way. ASTM sets the standard for calculating the PCI supported by surveying processes and calculation methods. The relevant ASTM standards are ASTM D6433 -11and ASTM D5340-12 [7].

Present serviceability index (PSI) In the early 1960s, the Present Serviceability Index (PSI) was developed with an inclusive effort to create performance standards based on riding quality. PSI's foundation is related to the values of rutting, cracking, patching, and pavement smoothness. The panel consists of highway users from various professions assessed different pavement sections and gave ratings on a five-point distinct scale (0 for poor and 5 for excellent) [14].

International roughness index (IRI) Another familiar concept introduced as an alternative index is the International Roughness Index (IRI) that has been approved to establish pavement performance. The IRI is calculated from the road surface profile and is computed by utilizing the surface elevation. The IRI has been applied broadly and characterized as a standard adopted by the Federal Highway Performance Monitoring System [14].

Structural ability evaluation

The ability of pavement to support traffic without developing great structural distress is known as structural capacity. The structural evaluation aims to assess the strength and the maximum allowable traffic loading by the pavement and forecast the pavement future service life [16]. Falling Weight Deflectometer (FWD) and Deflectograph are utilized to measure the pavement deflection as a non-destructive technique to assess pavements' structural capacity under the network and project levels [17]. The frequencies of traffic movement, including the structural condition, are utilized to establish the pavement structural capacity and prediction of pavements remaining life. Besides, the aircraft type

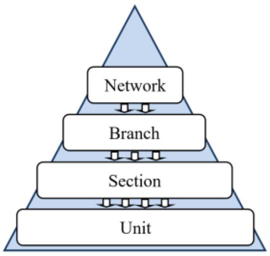

Fig. 3. Divisions of network classification in AMPS process.

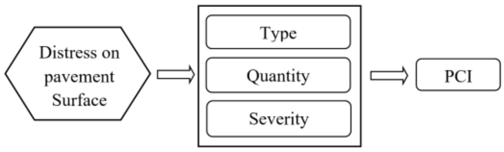

Fig. 4. Identification process of pavement condition index (PCI).

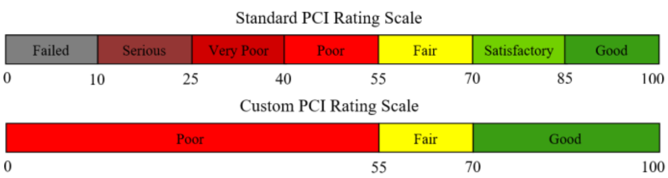

Fig. 5. Pavement condition index (PCI) rating (Adapted from [7]).

is also considered during the analysis of possible reasons for pavement deterioration and M&R strategies. Most of the aviation agencies utilize the ratio of Aircraft Classification Number to Pavement Classification Number (ACN/PCN) to represent the pavement load-carrying capacity [13].

ACN-PCN system The Aircraft Classification Number (ACN) corresponds to the aircraft's deterioration in the pavement subgrade. Each aircraft possesses a unique ACN for its tire pressure due to the aircraft weight finally imposed on the subgrade. Conversely, the Pavement Classification Number (PCN) represents the pavement's strength that withstands the aircraft loading. The higher the PCN is selected, the more damaging aircraft can operate in a particular pavement structure, and consequently, shorten the pavement's structural life. As a result, most airport pavements are designed as per the higher ACN generated by various aircraft and set the PCN accordingly [18].

Functional requirements

In particular, functional requirements for pavements affect the safe operation of aircraft. On the contrary, structural strength requirements usually affect the pavement's life. Aircraft pavement functional requirements that have a profound impact on aircraft operations are demonstrated in Table 1 [19].

Frequency of inspection and thresholds:

The authority should investigate an airport's functional conditions at 36–48 months and evaluate structural conditions through inspection of bearing capacity at 60-month frequency. The frequency of pavement inspection for the investigation of different index parameters such as rutting (RUT), estimated texture depth (ETD), deviation from a 3 m rolling straightedge (RSE) to be implemented for different surfaces as illustrated in Table 2 [1].

The threshold of different indices and the time of action are illustrated in Table 3 [1]. Nonetheless, rehabilitation actions are immediate when IRI, RUT, ETD, and PCI threshold values are equal or exceed the level of the critical condition.

5.4. *Technological application of pavement maintenance & management*

5.4.1. *Development of database*

The database development includes a compilation of collecting data relevant to the pavement section into a standard database file. The data are generated mainly during the review of existing records and during the evaluation of pavement. Some measures are taken to maintain the quality and integrity of the database [3].

5.4.2. *Customization of software*

The customization of software includes several activities such as the development of pavement performance models, improvement of prioritization guidelines, the detection of maintenance policies, and the inclusion of required unit costs for different M&R activities [3].

5.4.3. *Using instruments in pavements*

Advanced technologies now allow a more consistent and cost-effective field calculation of loads and stress measurement in-service conditions. Furthermore, some instruments can accurately measure the moisture condition, temperature, strain,

Table 1
Aircraft pavement functional requirements (Adapted from [19]).

Affecting factors	Functional requirement			
	Ride quality	Skid resistance	Freedom from FOD	Visual distinction
Construction quality	Yes			
Construction quality			Yes	
Contrasting flanks				Yes
Design surface levels	Yes			
Line markings				Yes
Pavement/subgrade subsidence	Yes			
Rubber contamination		Yes		
Subgrade shrink/swell	Yes			
Surface age		Yes		
Surface materials		Yes		
Surface materials			Yes	
Surface shape		Yes		
Surface treatments		Yes		
Surface treatments			Yes	
Sweeping frequency			Yes	
Wheel-path depressions	Yes			

Table 2
Frequency of pavement inspections (Adapted from [1]).

Index type	Frequency of pavement inspections (months)		Consideration in inspection
	Runway	Taxiway	
PCI	36	36	Pavement surface condition
PCN	60	60	Bearing capacity
IRI	36	48	Longitudinal and transversal regularity
RUT	36	48	Longitudinal and transversal regularity
ETD	36	-	Relief and verification of macro texture
RSE	36	48	Longitudinal and transversal regularity

Table 3
Threshold Values of different indices and the time of action (Adapted from [1]).

Index type	Pavement under the Network	Activity as per threshold					
		No action	Next inspection 4 months away	Rehabilitation within 1 year	Rehabilitation within		
					12 months	6 months	2 months
IRI	Runway	< 2.0	2.0 ≤ IRI < 2.5	2.5 ≤ IRI < 3.0		> 3.0	
	Taxiway and exit taxiway	< 3.0	3.0 ≤ IRI < 3.4	3.4 ≤ IRI < 3.8		> 3.8	
RUT	Taxiway/ taxiway	< 12.5	12.5 ≤ RUT < 25.0		> 25.0		
ETD	Runway and taxiway	> 0.75	0.40 < ETD ≤ 0.75	0.25 ≤ ETD ≤ 0.40			≤ 0.25
PCI	Runway and taxiway	>55	40 < PCI ≤ 55	25 < PCI ≤ 40			≤ 25
State		Regular	Acceptable	Pre-critical	Critical		
Chromatic Index							

and other relevant factors. In Chicago-O'Hare Airport, Henschen et al. (2014) [20] utilized dynamic strain gauges to examine the relative effectiveness of various isolation joint arrangements in the airport concrete pavements [21]. In New Jersey, Newark Airport installed strain gauges and thermocouples above and below the layer of an asphalt overlay to calculate the strain incurred by aircraft and supervise the propagation of horizontal shear deformation surface subsequently. At Shanghai Airport, Zhao et al. (2014) built concrete pavements with concealed strain gauges in a new runway pavement to receive responses [22]. Similarly, The University of Hawaii planned to conceal sensors in the asphalt overlay interfaces of an airport in Hawaii for their pavement management purposes [21].

GIS application

GIS (Geographic Information Systems) can render the pavement's visual information and spatial information, which can manage the accumulation of valid attribute data of airport pavement [23]. In the United States, GIS applications have been increased significantly over the last few years. As soon as the airport agencies understand that GIS application is beneficial for them, they started to incorporate several GIS applications [3]. In 1999, a study of U.S. airport executives revealed that more than 60% of airports were using (or had planned implementation) GIS to provide the necessary support to their pavement management actions [23].

5.4.4. Performance Models

Performance models in APMS forecast pavement performance over time, which helps determine the proper time to apply the required maintenance or rehabilitation to a section to return maximum benefits against the expenditure [3]. The expert modeling approach can be applied when insufficient data is available to generate the proper deterioration model with time [24]. Another standard method to create performance models isregression analysis (linear or nonlinear). Family is one frequently used type of regression analysis approach that can divide pavements up into groups (or families) that are anticipated to act in a similar way [25]. Different characteristics, such as surface types (Asphalt concrete [AC] and Portland cement concrete [PCC]) and functional classifications (runways, taxiways, aprons, or ramps), are employed while generating the pavement families. Afterward, performance models are fabricated based on available condition data to express a distinctive deterioration curve for each family's pavement sections. Mechanistic and Markov are two other methods available but have never been used in the history of APMS [3].

5.5. Prioritization & budgeting

5.5.1. Guidelines for prioritization

When the budget for M&R activities is inadequate in APMS, then sorting procedures and rankings of pavement projects are done following the prioritization guidelines. The basis of these guidelines is the agencies' experience, and practices and certain factors can be deployed to evaluate the pavement condition and the utilization of the pavement. Data analysis in APMS is divided into three main actions, which are condition analysis, needs analysis, and impact analysis [3].

Analyze the condition

Determination of the current state of the pavement networks' overall condition, reason for deterioration, and tempo of deterioration are involved in condition analysis. The reason for pavement deterioration can be divided into certain factors such as structural, climate, materials, age, or a combination of those factors. Some load-induced distresses alligator cracking and rutting on asphalt pavements and corner breaks in rigid pavements. Appropriate repair and maintenance alternatives can be evaluated if the reasons for pavement deterioration are identified [3].

Analysis of needs

Needs analysis to engage the development of an M&R schedule for the pavements under the management scheme. It also requires that a suitable M&R activity should be preferred for each pavement based on pavement performance prediction. Budget limitations are also in consideration during the fabrication of a need's analysis; therefore, the M&R actions must follow the rankings derived by prioritization. Annual prioritized M&R projects are listed in association with costs are the outcome of a successful need's analysis [3].

Impact analysis

An authority can assess whether the pavement network's overall condition is improving or deteriorating within certain budget restrictions by evaluating the trends over time. Another aspect of impact analysis is to establish an M&R backlog in the system. An agency can track the number of pavements is not given the required M&R due to budget limitations. The vital part of impact analysis is the ability to distinguish the various impacts based on different budget levels, which significantly benefit from leading the rehabilitation programs on the pavement network over time. APMS provides the necessary tools to conduct analysis and assist with the required graphics to envisage the network's impacts over time [3].

5.5.2. Maintenance and rehabilitation policies in association with the costs

Usually, APMS software can be customized to incorporate the M&R policies, which are considered by many agencies to use on their pavements. An APMS allows users to define specific factors that should activate the consideration of different pavement repair types, such as pavement condition level as a whole, rate of deterioration, and type of prevalent distress. Moreover, the maintenance and rehabilitation costs are included in most of the APMS software [3].

5.5.3. Selection of alternative strategies

APMS presents different options of M&R activities for each pavement based on the current and anticipated condition of the pavement sections. Generally, this future projection is founded on collected field data and laboratory examination results, the organization staff's experience, and expertise. They can be divided into deterministic or probabilistic models. The fixation of the most appropriate M&R strategy for a large pavement network requires expert knowledge of pavement conditions, the effectiveness of the strategies, and the impact of the performance of the system [13].

Life cycle cost analysis (LCCA)

Life cycle cost analysis (LCCA) is executed broadly in PMS to select the best alternative options and the optimum time for their implementation. The best-known method for measuring an action's efficiency should be its cost-benefit analysis [10]. Besides, the selection of the type of maintenance depends on the pavement condition and the expected life of the pavement.

5.6. APMS outputs

There are various ways of presenting the analysis results, for example, reports, tables, graphs, and maps. It is likely that engineers often prefer comprehensive reports containing detailed information. Graphical reports are found more effective since the concerned people get the idea at a glance without evaluating a large volume of data. APMS software program delivers various types of reports and different outputs depending on the type of software utilized. Some APMS software generates user-defined reports that enable the user to produce a report containing the chosen information. If GIS is incorporated with the software, then a GIS report can be developed [3].

5.7. Relevant issues in APMS implementations

5.7.1. Training process

During the APMS process implementation, proper training is necessary for individuals responsible for using this system. After completing the training program, the agency can have the personnel with the required skills to maneuver the system efficiently and effectively. It has been reported that the best results usually come when the training is ongoing all through the implementation process, and some provisions are prepared for periodic follow-up training [3].

5.7.2. Follow-up of APMS implementation process

It is significantly crucial that there must be an option of a follow-up plan in the APMS implementation process. The condition data must be recent and replicate the existing pavement conditions. The frequency of recurrent inspection mainly depends on the agency, their funding state, facilities in hand, and the available human resources to execute the assessment. One approach is to assess the runways annually and the remaining pavements components every 2 to 3 years if there is limited funding. In an APMS, some items will require revision periodically. Besides, when a new section is added into the system for some major rehabilitation work that alters the pavement management sections, the following essential items such as maps, the definition of database network, last date of construction and repairs, surface types, performance family assignments, and area of the sections need to be updated [3].

5.7.3. Performance observation and prediction

Since the availability of runways and taxiways is shrinking gradually for pavement investigation and maintenance activities, there is a strong need for more effective performance monitoring. There is also a significant desire that the pavement failures and distresses should be identified before their incidence. This directs cost-effective treatments to be executed in due time without disrupting the operations of the airport [21].

6. APMS practice and issues if different airports

6.1. APMS in different airports in the USA

In the USA, the Pavement Condition Index (PCI) system is used to evaluate pavements' overall performance. At present, the FAA is inspected various historical data and investigates techniques that can predict PCI more accurately over time that tends to perform well maintenance and rehabilitation programs as per requirements [21].

In Stewart International Airport, New York, Ground-penetrating radar and falling weight deflectometer testing were utilized collectively for the subsequent performance prediction model. The University of Texas has introduced a device that can capture surface profile, ground-penetrating radar, and detect the pavement deflection through a single pass [21]. Atlanta Airport launched a different approach of GPS based system that can able to develop an accurate map of aircraft movements at the ground around the airport. The accuracy of the map is 10 m, and it appears in real-time. In concrete pavements, the PCI of pavements were predicted based on joint spacing and age. Pittsburgh International Airport, USA, has a program that consists of three main components: a condition survey, a PCI calculation, and a maintenance and rehabilitation program. The pavement condition survey data is entered into the MicroPAVER pavement database that recommends the rehabilitation of a pavement section with PCI value below 55 [26].

6.2. APMS at Rome international airport

The Italian Civil Authority (ENAC) regulates the construction, maintenance, and management of Italian airports. At Fiumicino Intercontinental Airport, Rome is using visual condition data to predict next year's Maintenance and Rehabilitation (M&R) as part of APMS implementation. In addition to the visual rating, PCI is utilizing the defined pavements' structural and functional state. The Heavy Weight Deflectometer (HWD) provides the structural data required for mechanistic analysis.

A significant aspect of this type of APMS is that it utilizes historical information along with other data related to the structural condition, skid resistance, roughness, and visual condition. The outcome from the performance model is the optimal combination of M&R in certain budget levels over a number of years, including the structural design life. This type of analysis is termed as Life Cycle Costs Analysis (LCCA). The methodology mainly depends on using the mechanistic-empirical techniques for conducting performance and revealed the effects of rehabilitation. Elaborated cost analysis, including effect over a given period, can evaluate and discover the most excellent section-wise maintenance plans, which can be utilized in a network-based optimization within a constraint budget [27].

6.3. APMS in Australia

Different engineering consultants have become the preliminary designers and set specifications for airport pavements after privatizing major airports in Australia. The specifications are guided by different models introduced by various Commonwealth departments, including new technologies [19].

Different approaches have been taken into consideration to forecast pavement performance in Australia. Australia's currently available systems include ground-penetrating radar surveys, falling weight deflectometer (FWD) surveys, and high-resolution surface scanning. Some other systems, such as the PCI, are less pertinent to Australian airports since there is a difference in airport maintenance and improved funding responsibilities than in the USA [21]. Nonetheless, the Department of Defence can apply PCI or a similar system since Defence manages around 20 airfields across the country and conducting annual inspections by involving numerous personnel in this mechanism. Certainly, PCI would render a high level to the Defence compared with overall circumstance across their pavement inventory [21].

6.4. GIS & GPS application in Chinese Airport under SHAPMS

In 2005, the Shanghai airport pavement management system (SHAPMS) was introduced to develop Hongqiao and Pudong International Airports. Chen et al. [23] conducted a study on the airport pavement management system to improve and develop the most appropriate maintenance and rehabilitation techniques in the airport pavement system. The data were collected manually by using GPS techniques by using a Trimble Real-time sub-meter GPS receiver, including a field computer. GIS was utilized to point out the location and position of the slab of distresses. The survey operated by dividing the full width into several segments to determine the PCI of each section, and it expressed that some of the sections need maintenance since it was not acceptable as per the requirements of aircraft operations [23]. The study's main outcome was that using a technological instrument could lessen the pavement condition survey duration, and GIS and GPS technology-based pavement assist the engineers in obtaining data reliability [2,23].

6.5. Case studies on surface distress of airport pavements in Japan

Hachiya et al. [28] performed research and intended to utilize the APMS to assess and rehabilitate the pavement of Osaka Itami Airport. The pavement surface assessment and structure were done using the Pavement Rehabilitation Index (PRI) to help make decisions for rehabilitation or maintenance work. Afterward, the results were compared with the other surveys conducted in the past 20 years. The pavement surface condition evaluation was done every three years, based on the surface condition, and the PRI method decided if there any rehabilitation was necessary to any section. The assessment of the structural condition was completed by the PRI method and by using the Falling Weight Deflectometer (FWD). The pavement condition is divided into three types of rank A, B, and C based on the PRI results. The results indicate that the condition of the pavement surface in the runway is better than the taxiways condition, according to the survey conducted 20 years ago. Considering the current PRI values, it can be determined that no rehabilitation is needed, and the airport's pavements are in a state of well-maintained [2,28].

7. Distresses

Different distresses are frequently occurring in asphalt pavement, which needs to be appropriately identified for rectification purposes. These are mainly alligator cracks, bleeding, polished aggregate block cracking, corrugation, depression, jet blast, erosion, joint reflection cracking, longitudinal and transverse cracking, oil spillage, patching, raveling, rutting, shoving of asphalt pavement, slippage cracking, swell, and weathering (surface wear). Each distress is identified and measured from low, medium to high severity levels [29,30].

8. Guidelines to distress and maintenance

The FAA advisory circular A.C. 150/5380-7B discusses basic essential components of pavements and produce cost-effective solutions regarding pavement maintenance and rehabilitation (M&R) under the Airport Pavement Management Program (PMP) concept [7]. Several comprehensive guides include the most important and familiar maintenance activities for various pavement and surface types, are shown in Table 4. These guides provide information and suggestions regarding the process of airport pavement inspection, airport pavement management systems, determination of the type of defects and distresses for both flexible and rigid pavements, and the most familiar treatment applied against different distresses, and references to other guidelines [19].

Table 4
Different Guides to airport pavement inspection and maintenance (Adapted from [19]).

Title of the Guidelines	Publisher
Guide to Airport Pavement Maintenance	Ministry of Defence (U.K.)-1994
Airfield Pavement Condition Survey Procedures	U.S. Army Corps of Engineers-2004
Implementation of an airport pavement management system.	Transportation Research Circular, (E-C127)-2008
Common airport pavement maintenance practices, ACRP synthesis 22.	Transportation Research Board(USA)-2011
Inspections of Airfield Pavements	Ministry of Defence (U.K.)-2011
Guidelines and Procedures for Maintenance of Airport Pavements	FAA(USA)-2014
Airport Pavement Maintenance Manual	Department of Defence (Australia)-2015

9. Expert system for APMS

The expert system is a knowledge-based computerized software program that mimics human skills in the reasoning process and solves specific problems in a narrow domain. An expert system's benefit over human expertise is that they are consistent and affordable, set permanently once documentation is completed, and easy to access while human expertise is perishable, expensive, and non-transferable. Some expert systems which have been introduced for airport pavement management are PAVER, AIRPORTS, AIRPAVE, AIRPACS, AirScene™, and PAVEAIR.

In 1968, USA-CERL began developing PAVER Pavement Maintenance Management System after realizing the urgent needs for cost-effective management treatment under M&R budgets [14,25]. The PAVER prediction modeling, including GIS and other capabilities, helps define climate and other factors that could affect the pavement [2]. In 1997, Dynatest invented AIRPORTS that utilizes skid resistance, surface profile data for analysis, and PCI for pavement evaluation. AIRPAVE considers three different rating parameters to assess the pavement are Functional Index (replicates riding quality), Structural Index (indicates the bearing capacity of pavement), and Mechanical Index (represents wearing course condition), respectively [31]. AIRPACS exercised mechanistic and empirical design method to determine treatment about layer thicknesses and joint spacing requirements [13]. The AirScene™ used to calculate the pavement damage generated by each aircraft's movement and thus convey pavement conditions based on initial data and the computations of accumulated damage over time. PAVEAIR utilizes US FAA software to prevail over the functional and structural performance of pavement and design purposes [31].

10. Conclusion

This study aims to provide an overview of the APMS for profound knowledge and understanding of its successful implementation. Pavement Management System (PMS) is a useful tool, including a systematic procedure for collecting, analyzing, maintaining, and reporting pavement conditions and thus assists airports in finding optimum cost-effective M&R treatments for their pavement network. PMP's significant components include database compilation, construction & repair history, as-built records for analyzing solutions, chronological history of pavement maintenance and rehabilitation history, current and anticipated future traffic data. A computerized software program is an integral part of this system for computing precise analysis and providing suggestions on M&R strategies. By projecting the rate of deterioration, a life cycle cost analysis can be made for various alternatives to identify the optimal time to apply the best M&R alternative and avoid higher M&R costs in the future. PMS cannot give an ultimate decision; it only conveys the scenarios of alternatives and indicates the possible consequences so that concerned human expertise can apply the appropriate, cost-effective solutions for on-time implementation.

Different pavement condition indices are using to evaluate the pavement condition and set the priority ranking for treatments. PCI is the most adopted index that utilizes visual inspection for condition assessment In the USA and many other countries. However, Pavement Rehabilitation Index (PRI) has been utilized in an experiment in Japan for pavement structural condition assessment and rehabilitation actions. International Roughness Index (IRI) is applied broadly by the Federal Highway Performance Monitoring System in the USA. Different airports are shifting towards APMS from the traditional maintenance system. More research and studies are required in airport pavement management since there is a deficit in the information regarding the APMS on different airports globally.

Finally, the study provided a comprehensive collection of information required to implement APMS. Consequently, airport operators are in a far more informed position to forecast future pavement maintenance requirements to maintain overall airfield conditions adequately. The review found that unlike PMS for road, the literature on APMS for airports worldwide is rather limited, and there are also very few publications relating to the airfield pavement deterioration modeling in APMS.

Reference

[1] P. Di Mascio, L. Moretti, Implementation of a pavement management system for maintenance and rehabilitation of airport surfaces, Case Studies Constr. Mater. 11 (2019) e00251.

[2] M. Qabaja, A. Labeedi, An investigation of the airport pavement management system (APMS), Inter. J. Adv. Eng. Sci. App. 1 (1) (2020) 27-33.

[3] S. L. Tighe, M. Covalt, Implementation of an airport pavement management system, Transp. Res. Circular (E-C127) (2008).

[4] M. Broten, C. Comer, A. Muntasir, State airport pavement management practices and the impact on pavement condition, 6th International Conference on Managing Pavements, Queensland, Australia, 2004.

[5] M. M. Rahman, Alternatives to PCI and MicroPAVER based maintenance solutions for airport pavements, (Master thesis), University of New Mexico, NM, USA, 2013 https://digitalrepository.unm.edu/ce_etds/73.

[6] G. Chai, R. Bartlett, G. Kelly, L. Yang, L., E. Oh, Model for Benchmarking Pavement Maintenance Budget for Sustainable Road Transport Infrastructure, Geotechnical Special Publication, Geo-China, Shandong, China, 2016, pp. 180-187.

[7] Federal Aviation Administration, Airport Pavement Management Program (PMP). Advisory Circular 150/5380-7B. FAA, Washington, USA, 2014.

[8] S. G. de Oliveira, A. Tibaut, G. Dell'Acqua, Airport Pavement Management Systems: An Open BIM Approach, International Symposium on Asphalt Pavement & Environment, Padua, Italy, 2019, pp. 450-459.

[9] J. Hajek, J. Hall, D. Hein, Common airport pavement maintenance practices. ACRP synthesis 22. Transportation Research Board, Washington DC, USA, 2011.

[10] R. Haas, W.R. Hudson, J. Zaniewski, Modern Pavement Management, Krieger Publishing Company, Malabar, Florida, 1994.

[11] M. Y. Shahin, K. A. Cation, M. R. Broten, Micro PAVER Concept and Development Airport Pavement Management System. Construction Engineering Research Lab (ARMY) Champaign, IL, USA,1987.

[12] S. G. Ritchie, C. Yeh, J. P. Mahoney, N.C. Jackson, Pavement Rehabilitation Planning, J. Transp. Eng. 113 (2) (1987) 185 https://doi.org/10.1061/(ASCE)0733-947x(1987)113.2(185)

[13] N. Ismail, A. Ismail, R. A. O. K. Rahmat, Development of expert system for airport pavement maintenance and rehabilitation, European J. Sci. Res. 35 (1) (2009) 121-129.

[14] K. Wu, Development of PCI-based pavement performance model for management of road infrastructure system, Arizona State University, AZ, USA, 2015.

[15] American Society for Testing and Materials, Standard Test Method for Airport Pavement Condition Index Surveys. ASTM D5340-12. ASTM International, West Conshohocken, PA, 2018.

[16] M.W. Witczek, Framework for Evaluation and Performance of Airport Pavements, Special Report 175, Transportation Research Board, Washington DC, USA, 1978, pp. 69-75.

[17] K. Loganathan, M.M. Isied, A.M. Coca, M. I. Souliman, S. Romanoschi, S. Dessouky, Development of comprehensive deflection parameters to evaluate the structural capacity of flexible pavements at the network level, Inter. J. Pavement Res. Technol. 12 (4) (2019) 347-355 https://doi.org/10.1007/s42947-019-0041-0

[18] G. White, Regional airport pavement challenges and innovations, IPWEA Annual Conference, Queensland, Australia, 2018.

[19] Australian Airports Association, Airport practice note 12–airfield pavement essentials, AAA, Canberra, Australia, 2017.

[20] J. D. Henschen, A. N. Amirkhanian, J. R. Roesler, D. A. Lange, Field evaluation of alternate isolation joints at O'Hare international airport, Proceedings 2014 FAA Worldwide Airport Technology Transfer Conference, Galloway, New Jersey, USA, August 5-7, 2014.

[21] G. White, New airport pavement technologies from the USA, Proceedings 2014 Australian Airport Association National Conference, Gold Coast, Australia, 2014, pp. 23-27.

[22] H. Zhao, L. Wang, J. Yuan, The pavement condition monitoring system at Shanghai Pudong international airport, Proceedings 2014 FAA Worldwide Airport Technology Transfer Conference, Galloway, New Jersey, USA, August 5-7, 2014.

[23] W. Chen, J. Yuan, M. Li, Application of GIS/GPS in Shanghai Airport pavement management system, Proc. Eng. 29 (2012) 2322-2326.

[24] K. Zimmerman, M. Broten, Development of Performance Models for Pavement Management System, 24th International Air Transportation Conference, ASCE, Montreal, Canada, 1999.

[25] M.Y. Shahin, J.A. Walter, Pavement Maintenance Management for Roads and Streets Using the PAVER System. U.S. Army Corps of Engineers (USA CERL). Champaign II, Technical Report M-90/05. IL, USA, 1990.

[26] N. I. Hadi, R. Papa, Y. Wang, Understanding Pittsburgh International Airport's Pavement Management Program, Pittsburgh, PA, USA, 2010.

[27] A. Marradi, M. Tamarozzi, Pavement Management System Implementation At Rome Fiumicino International Airport. (Airport Review, 2010), https://www.internationalairportreview.com/article/3433/pavement-management-system-implementation-at-rome-fiumicino-international-airport. Accessed 18 August 2020.

[28] Y. Hachiya, T. Watanabe, K. Kitaochi, Some Issues on Surface Distress of Airport Pavements in Japan, Service Center of Port Engineering (SCOPE), Tokyo, Japan, 2013.

[29] American Public Works Association, Asphalt Surfaced Airfields, Paver Distress Identification Manual. United State: U.S. Army Corps of Engineering, IL, USA, 2009.

[30] ERDC-CERL, PAVER™ Distress Identification Manual: Asphalt Surfaced Roads and Parking Lots, U.S. Army Corps of Engineers, USA, 2009.

[31] A. D. Hamed, A. Riza, I. Amiruddin, Advisory Expert System for Implementation of Airfield Pavement Management System, Regional Engineering Postgraduate Conference (EPC), Malaysia, 2011.