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A Review of PMS systems and How Can be Implemented in Al-Qassim Municipality Roads

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Abstract— *In recent years, a pavement management system (PMS) has been widely used by highway agencies to manage their roads effectively, especially with significant increases in traffic loadings, limited budget, aging of pavement network, and improper road design and construction. AL-Qassim region, Saudi Arabia, is facing enormous challenges in dealing with pavement networks because the current pavement management system is not capable to maintain the pavement network at desirable condition, leading them to taking improper decisions regarding maintenance and rehabilitation activities. Therefore, it is important to maintain the current roads at an acceptable level of service by coordinating the maintenance works and evaluating the pavement condition periodically to reduce the deterioration rate. The goal of this paper is to review the practiced PMS and study how it can be implemented in Al-Qassim roads with some adjustments. The proposed PMS will assist the decision-makers in Al-Qassim municipality in planning the maintenance and rehabilitation works during the roads design life.*

Keywords— ***Municipalities, Pavement, PMS, Roads, Saudi Arabia.***

I. INTRODUCTION

The PMS has been applied widely by highway agencies to manage the pavement network and assist engineers and decision-makers. The decision-makers can rely on the PMS to select the optimum strategies and schedule maintenance activities for preserving the pavement network at the desired level of services based on cost-effective analysis and the available funds. The main task of a PMS is to provide the highest pavement quality with limited resources [1]. The pavement is a complex structure to deal with as it is influenced by various factors such as environment, materials, and traffic loads [2]. The American Association of State Highway and Transportation Officials (AASHTO) defined the PMS as "a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time" [3]. An effective PMS requires data from different sources which include data related to pavement performance, section description, historical, policy, geometry, environment, and cost [4]. The implementation of applying an effective PMS should be done through the several steps which are: pavement condition survey, pavement assessment, life cycle cost analysis, and defining the alternative strategies for maintenance [5].

Although the concepts of PMS began in the early 1970s, and the effects of PMS have been proven, many highway agencies have not applied these concepts for maintaining their road networks. Therefore, there is a need to explain and simplify the PMS concepts and their impact on road conditions, especially with limited funds.

In Al-Qassim region, the municipality engineers use their judgments for evaluating pavements and maintenance decisions. Therefore, it is necessary to introduce the concepts of pavement management and initiate the PMS for Al-Qassim municipality. This paper can help and simplify the concept of PMS and its implementation in Al-Qassim cities for managing their roads networks.

The main goal of this paper is to review the PMS and improving the current practice of pavement management in Al-Qassim region, Saudi Arabia, by clarification the required data that should be collected for the inventory and the required steps for establishing the modern PMS.

II. PROBLEM STATEMENT

Al-Qassim region is located in the center of Saudi Arabia as one of the thirteen administrative regions of the kingdom as shown in Fig. 1. The current population of Al-Qassim is around 1,455,693 living in an area of 58,046 km^2 [6]. Two major highways pass through the Al-Qassim region; Highway 65 connects from south to north of the kingdom, and Highway 60 connects from west to east.

Fig. 1: Map of Saudi Arabia with Al-Qassim region outlined [7]

In July 2020, the Saudi Council of Ministries approved that the jurisdiction of the executed and future roads within the urban boundary of the Ministry of Municipal and Rural Affairs and within its responsibilities, and the jurisdiction of the executed and future roads outside the bounder of the urban area of the Ministry of Transport and Logistic Services and within its responsibilities. The total lengths of roads that are under the Ministry of Transport and Logistic Services are around 71,500 km and they have been designed and built based on a high level of standards specifications [8]. In 2018, the Ministry of Transport and Logistic Services built 1,721 km in the kingdom as new roads, of which 77.12 km were in the Al-Qassim region, moreover, there were 67,027 km in the kingdom, of which 6,492 km were in the Al-Qassim region [9]. In 2019, the Ministry of Transport and Logistic Services spent $1.15 billion (4.3 billion Riyals) on highway maintenance activities for three years from 2019 to 2022 [10].

Al-Qassim municipality is responsible for existing roads with lengths of 11,216.7 km, 667.8 km under construction, 1408.8 km proposed for the building, and 5 bridges up to the end of 2019 [11]. By the end of 2020, Al-Qassim municipality has maintained and rehabilitated around 163888 m^2 of Al-Qassim roads [11]. The total lengths of roads that were exposed to maintenance and rehabilitation process in 2016 were 34 km of major roads and 8.3 km for local road [12]. The increasing of actual executed roads' length, under construction roads' length, and proposed roads' length are shown in Fig. 2. After applying the aforementioned legislation, the Al-Qassim municipality will be responsible for all roads within cities such as the ring road of Buraydah (the capital of Al-Qassim region) with 73 km and 18 bridges, moreover, the 31 km internal ring road. Therefore, these roads should be managed and maintained in a proper method to improve their conditions and serviceability. The proposed PMS should be able to generate comprehensive, simple, and valuable reports that can be relied on by the decision-makers.

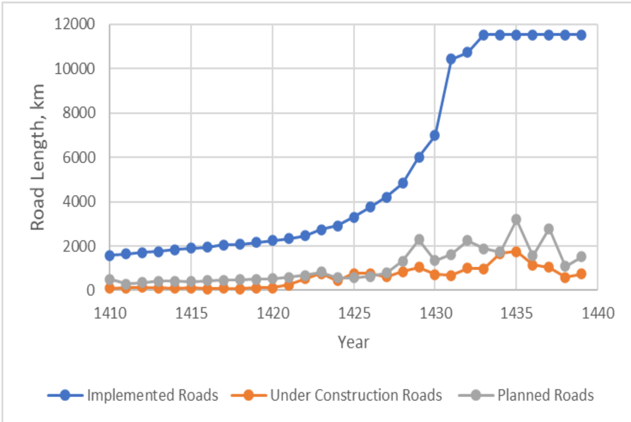

Fig 2: lengths of implemented, under construction, and planned roads in Al-Qassim region

Nowadays, governments across the world are facing a dilemma as a result of the COVAID-19 pandemic, so they are increasing spending on certain sectors such as health care, small and medium enterprises, and logistics, also, they cut some commitment infrastructure spending to stimulate their economies. Therefore, highway administrations should adopt an effective tool to distribute the reduced budget on their roads based on systemic methods.

III. THE PMS REQUIRED STEPS

The main objective of this research is to provide simple and effective guidelines for applying the PMS for Al-Qassim municipality. Before applying the PMS, a new department or committee should be forming containing several pavement engineers, Geographic Information System (GIS) operator, statistical analyzer, and Information Technology (IT) technician. The responsibilities of the recommended department are making sure the PMS working as planned, modifying the PMS to meet the municipality's needs, and generating reports and recommendations.

The elements of proposed PMS are collecting pavement condition data, establishing criteria for pavement assessment, prediction models to predict pavement performance, and establishing strategies for pavement maintenance. The proposed PMS for Al-Qassim municipality is presented in Fig. 3.

The proposed PMS includes all basic steps of PMSs that have been applied by highway agencies. The steps of the proposed PMSs are defined in the following sections.

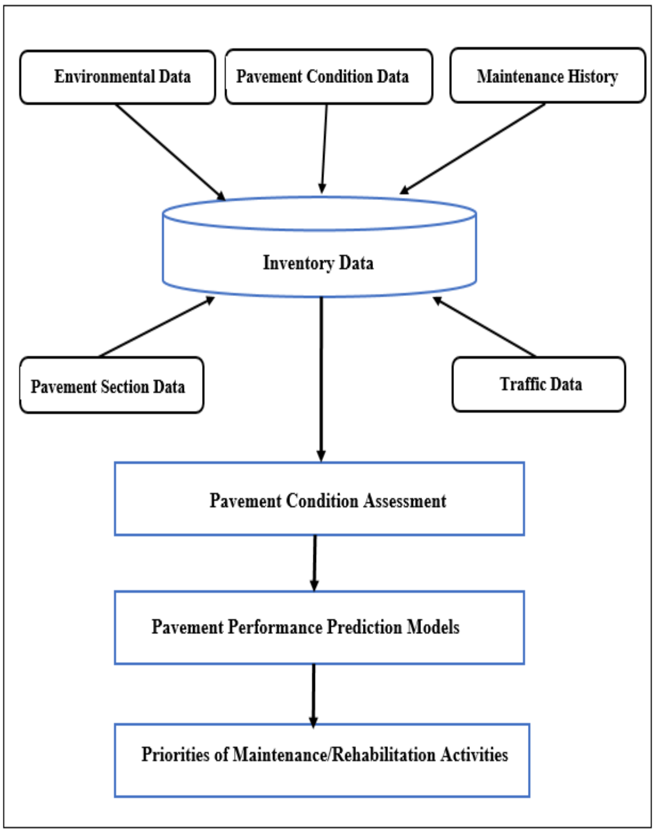

Fig.3: Proposed framework for Al-Qassim PMS

A. *Inventory Data*

The first step of the PMS process is collecting all data relevant to the management of the pavement network. Inventory data are a very important step in any PMS because the inventory data include data of environment, traffic loads, pavement condition, maintenance, and geometric data. The following sections contain the required data for having an effective PMS.

1) *Pavement Section Data*

The inventory data should cover the entire pavement network by dividing the roads into sections, and each section must be identified by beginning and ending stations, and each section is referenced through a Global Positioning System (GPS). AASHTO (2012) recommended that each pavement segment in inventory should include: segment length and location (beginning and ending points), road functional classification, pavement and shoulder type, number of lanes, drainage information, pavement age, and layer thicknesses [13].

2) *Traffic Data*

Traffic data is a fundamental factor in any PMS for predicting pavement performance, and the traffic data is collected as average annual daily traffic, truck percent, traffic growth or Equivalent Single Axle Loads (ESALs) [4]. Collecting accurate traffic data leads to knowing the priorities of maintenance activities which can be used to allocate the available budget of maintenance [5]. The magnitude of loading, axle configuration, and the number of load repetitions have a large influence on pavement performance and significant factors that can cause damage to the pavement [14].

3) *Environmental Data*

Including the environmental data into the PMS can assist decision-makers in predicting pavement performance and selecting the proper maintenance action. Minimum temperature, maximum temperature, freeze-thaw cycle, and seasonal rainfall impact on pavement deterioration rate by changing the material properties of pavement surface and sublayers, therefore, the environmental factors should be included in the inventory data. The National Cooperative Highway Research Program (2004) reported that the strength of all layers including the asphalt layer, unbounded materials, and subgrade are significantly impacted by the environmental factors [15].

4) *Pavement Condition Data*

Pavement condition data is a significant component of data inventory for PMS because it is used to compare pavement sections in the network to find the best solutions option for applying the maintenance action. Most of the highway agencies conduct periodic pavement condition surveys usually every two years, and the collected data should be in reasonable detail based on the available budget and tools [16]. For asphalt pavement, the collected data are roughness, rut depth, transverse cracking, fatigue, non-load-related cracking, shoving, potholes, bleeding, raveling, and polishing [17]. The two common ways to determine the pavement condition are International Roughness Index (IRI) which measures the irregularities in the pavement surface and the Pavement Condition Index (PCI) which mainly includes most pavement distresses [1]. Hass (1994) explained the relationship between the level of detailed data and types of decisions in the process of pavement management as shown in Fig. 4 [4].

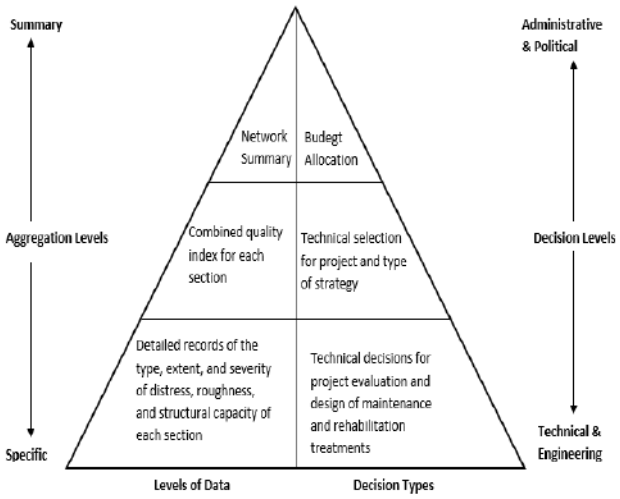

Fig.4: Level of data aggregation and decisions

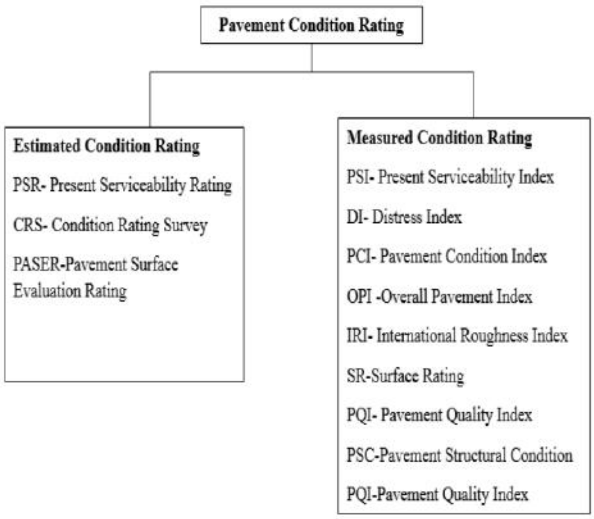

Fig.5: Pavement evaluation systems

5) Maintenance History

Maintenance data include information on all maintenance and rehabilitation types and their effects on pavement performance. Also, knowing the history of performed maintenance with associated cost provides a clear indicator of the effectiveness of each maintenance activity for calculating life cycle cost analysis. Collecting periodic maintenance data over time is necessary to fulfill the PMS purpose because the maintenance action can greatly affect the reliability of performance prediction models [18].

B. Pavement Condition Assessment

The main reason for collecting the pavement condition data is for reporting the pavement conditions of all pavement sections. The combination of the individual measures is sufficient for indicating the overall quality of pavement conditions to be used for communications between engineers, the public, and administrators. Accurate evaluation of pavement conditions leads to proper decisions for maintenance and rehabilitation activities. The pavement assessment tools range from visual inspections to sophisticated processes, such as video and image analysis [19]. However, the critical task is how to convert the collected data into overall pavement condition indices that include the extent and severity of ride quality, pavement distresses, structural capacity, and skid resistance. Fig. 5 represents the examples of rating systems either as measured or estimated approaches [20].

C. Pavement Performance Prediction Models

The concept of pavement performance means that the ability of pavement structure to serve under-considered traffic loadings and climate factors [3]. Pavement performance prediction models consider a critical element of any PMS, and reliable prediction models are needed for having an effective PMS, therefore, highway agencies should develop resilient prediction models for their roads to predict the future performance of pavements under traffic and environmental factors. The prediction models can assist road engineers and decision-makers to identify when, where, and what treatment actions should be taken. Moreover, AASHTO (2012) reported that pavement prediction models can play important role in terms of estimating future pavement conditions, identifying the suitable time for applying maintenance, analyzing the cost-effectiveness of each treatment for pavement network, and establishing criteria for warranty contracts and performance specifications [13]. Hence, the performance of each pavement section is illustrated to demonstrate the future performance of existing pavements and the rehabilitation alternatives in the needs year as shown in Fig. 6.

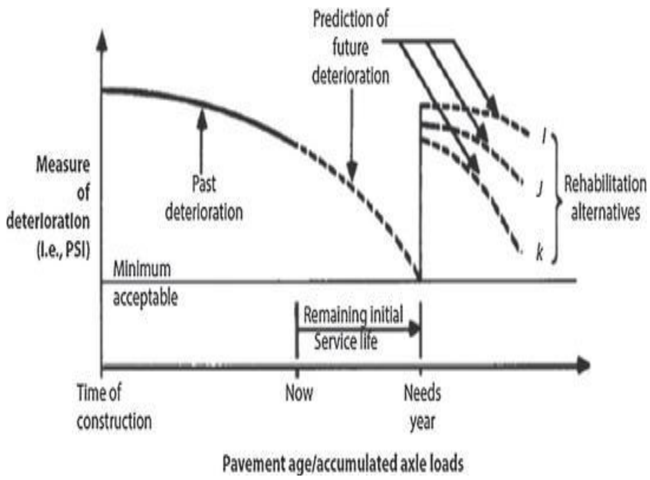

Fig.6: Pavement performance curve over time [4]

The typical pavement performance prediction models relate a performance indicator to one or more significant variables affecting the pavement performance such as traffic loadings, environmental factors, pavement structure, and material properties. The common pavement performance indicators are pavement condition index (PCI), present serviceability index (PSI), and international roughness index (IRI) [21]. Currently, the performance prediction models are classified into empirical, mechanistic-empirical models and their applications are based on the availability and quality of data [22].

D. Priorities of Maintenance/Rehabilitation Activities

The major output of PMS is applying the best treatment for the pavement sections which leads to optimizing the roadway network. Therefore, planning and prioritizing the pavement maintenance and rehabilitation activities can enhance the roadway network by extending the pavement service life, improving riding quality, and reducing vehicle operating costs. Different factors should be considered when selecting maintenance and rehabilitation strategies. These factors are how worse the pavement condition, available budget, traffic volume, and cost of proposed treatment action. The basic strategies for maintenance and rehabilitation actions are shown in Table 1 [23].

Table 1: The basic strategies for maintenance and rehabilitation strategies

Maintenance and rehabilitation actions	***Action description***
Routine maintenance	Defined as a planned maintenance action that should be performed on a schedule to store the roads at a required level of service.
Preventive Maintenance	Defined as a type of maintenance action that is designed to correct deterioration before getting into a worse condition.
Deferred action	This action is applying when the pavement condition is getting into the point that routine and preventive maintenance are not feasible for applying and no need for major rehabilitation.
Rehabilitation action	This action is an extensive corrective action that can extend the road service life when the routine, preventive, and deferred actions are no longer cost-effective.
Reconstruction action	This action is undertaken when the road cannot carry the traffic loads safely, and the other maintenance actions are not feasible to perform.

It is important to take the proper decisions for maintaining pavements based on type and severity of distress. The most common distresses for asphalt pavements are rutting, roughness, raveling, cracking, bleeding, and weathering and their treatments are either routine maintenance, surface seal coats, milling, and inlays, thin overlay, thick overlay, mill, and overlay, or reconstruction [13]. Each treatment should be applied based on trigger rules which include surface type, pavement age, pavement condition, and traffic volume. These trigger values are determined by engineers who have experience with treatment options and pavement network. The trigger values approach determines the feasibility of applying maintenance activities for each pavement section in the network, and it can be visualized as a decision tree or matrix to be easier for use by engineers and decision-makers. Fig. 7 shows the decision trees that was developed by the Ministry of Transport in Ontario (MTO) to determine the proper treatment decision and at each branch in the tree, specific option should be identified [24]. Also, Champaign County in Illinois uses a matrix to determine the proper treatment based on PCI, structural capacity, traffic volume, and as shown in Fig. 8 [25].

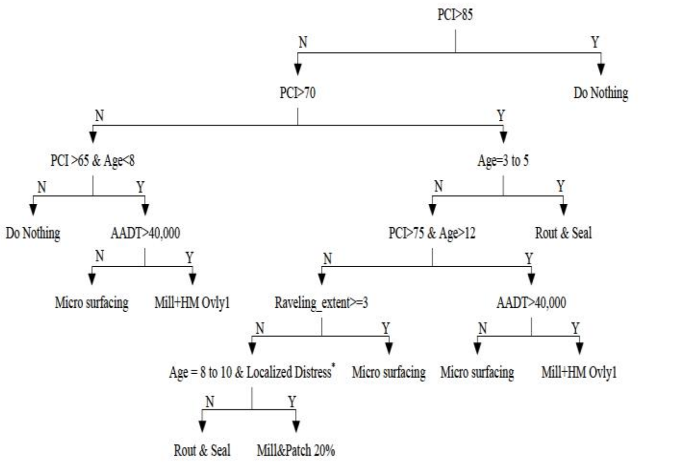

Fig.7: The MTO decision on the tree that used for determining the treatments

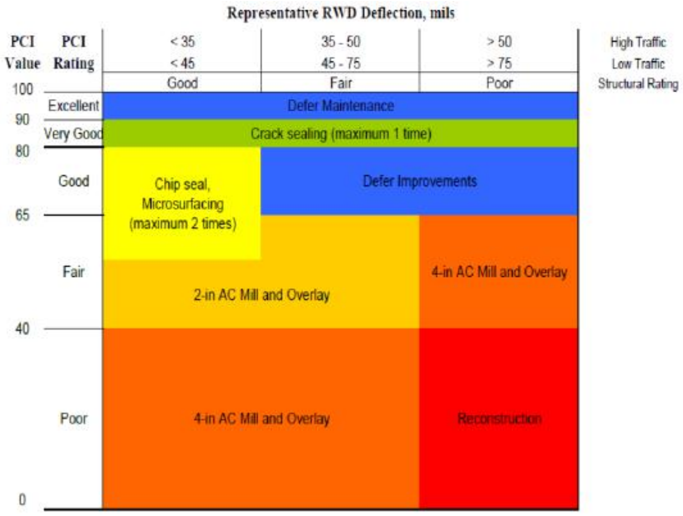

Fig. 8: Champaign County matrix for selecting treatments

The previous section discusses the feasible approach for the selection of proper treatment for pavements within the network. In general, the available funds for municipalities to repair their roads are not sufficient to fix all road segments in the network. Therefore, it is important to priorities the projects for consuming the available budget as wisely as possible. Ranking and benefit-cost analysis approaches have been widely utilized to priorities the maintenance and rehabilitation projects over the road network when there is insufficient budget.

A ranking approach is a simple approach to rank the projects based on agency criteria such as pavement condition and/or traffic level. In the ranking approach, the road sections are repaired based on the worst first strategy until consuming the available fund. The drawback of this approach is the cost-effective analysis is not considered which means the pavement network is not managed for long-term strategy.

A benefit-cost analysis approach is favored over a ranking approach as the cost-effectiveness is considered in terms of treatment types and impact of delaying or accelerating a treatment. The benefits in PMS are considered the additional performance provided after applying the treatment which is represented as a benefit area in Fig. 9. The benefit-cost ratio is calculated as a treatment benefit (area under performance curve after applying the treatment) divided by the treatment cost.

The road departments now have two options to priorities their projects either by using ranking or cost-effective analysis and that is based on the available fund.

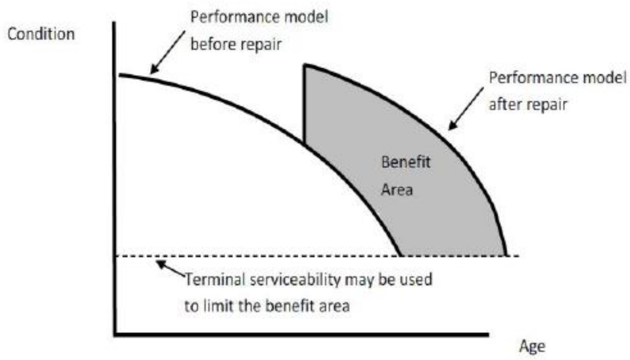

Fig. 9: Benefit calculation using the benefit performance curve [13]

IV. CONCLUSION

The paper reviewed the current practice of PMS and recommends the Al-Qassim municipality engineers to implement the PMS through collecting and store data, predicting future pavement performance, and applying effective treatments for the roadway network in the Al-Qassim region. Currently, the assessment of road conditions in most cities is not widely managed properly and the maintenance decisions are not made based on economic evaluation. Therefore, the PMS can play a significant role in the acquisition-related data, evaluation pavement condition, and allocating maintenance budget effectively. It has been proven that applying a PMS is better than working without any systemic approach for managing the roads network. The road agencies in Saudi Arabia should conduct a feasibility study for implementing a PMS for their roads. The potential costs for applying the PMS are the cost of collecting and storing data, acquisition of software and personal training, and cost of required maintenance and rehabilitation activities. The benefits of having a PMS can be included in two main outputs; maintaining the pavement condition of the road network at a desirable level, and allocating the available maintenance budget on the network effectively.

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