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World highways pavement management system: an overview

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Abstract

In all countries around the world, roads and highways constitute a vital and significant component of the transportation infrastructure and are crucial for the growth of local economies and societies. The term "Pavement Management System" (PMS) refers to a precise and systematized arrangement of defined procedures for collecting, analyzing, maintaining, and reporting pavement data that enables decision-makers to identify the most suitable arrangements and strategies for maintaining the pavements in the functional order for a given specific period at the least profitable cost. To maximize results within a certain budget, the system will next prioritize and suggest pavement rehabilitation and maintenance. The maintenance system in use tracks a variety of elements, including the cost of the activities required to conduct maintenance and the types of materials, personnel, and equipment. After segmenting the road into sections, this technique uses visual or automated field inspection, and its data is subsequently entered into a database. Following the analysis of this data, either by software or by a subject-matter expert, recommendations for the project will be given in the future. Next, based on the budget that is available, the type of surface, and the state of the road, the PMS develops a deterioration curve for each segment of the road. Finally, it chooses the best cost-effective maintenance approach. All of this is precisely accomplished using a PMS, which offers the right pavement treatment at the right time to extend the pavement's life for a reasonable amount longer and at a lower maintenance cost.

Keywords: *Highway, Transportation, Materials, Deterioration, Budget*

1. Introduction

Pavements are a crucial component of the world's transportation infrastructure since road networks serve as connections between businesses, industries, and customers and have a big impact on the economy and the growth of a country. Environmental factors significantly affect the road network since continued traffic can deteriorate the condition of the pavement, which has an impact on the comfort of rides and the costs incurred by road users. Thus, it is essential to use a suitable system to manage those roads in order to preserve the pavements in good or desired state for a longer period of time. Long-term economic costs were considerable due to inadequate investment or ineffective maintenance techniques. In order to maintain roads at the lowest possible cost and to extend their service life for as long as possible, the PMS has been activated and developed [1]. By analyzing the pavement program, the PMS helps to create an acceptable technique for managing the road network [2]. In order to help highway managers create a road network that is rational, consistent, and economical, this methodology should seek to deliver information that will help them make essential judgments.
In its widest meaning, pavement management entails overseeing all tasks connected to the pavement network. Planning and programming, design, building, maintenance, and restoration are only a few of these tasks. Effective pavement management tools and procedures can aid policymakers in developing long-term strategies for building and maintaining a safe and functional roadway network (the planning horizon). An organized and systematic approach to pavement management activities by entities is required for a successful PMS (state or municipal, public or private) [3-5].
Since the early 1970s, pavement management systems (PMSs) have been in use, with varying degrees of success in full deployment. When talking about decision-makers and upper-level management, however, things change. Managers of

maintenance and operations and engineers specializing in pavement management understand the value of a PMSs. They are more interested in benefits with monetary worth ($) than the conventional benefits stated in the literature [2, 6].
The infrastructure of a country includes things like roads, railways, ports, airports, and communication, which enable people to go about their everyday lives and carry out industrial tasks. It is crucial to gauge a country's economic expansion [2, 7].
The American Association of State Highway and Transportation Officials (AASHTO) provides the following definition for the term (pavement management) 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 [8]. As ancient as the first pavement is the idea of building pavements and keeping them in good shape. As pavement networks expanded slowly in the first half of the 20th century then rapidly in the 1950s and 1960s, simple methods and past knowledge no longer worked. A more comprehensive systems approach was required.
In the late 1960s and early 1970s, PMS was used to describe a set of decision support tools for pavement provision and maintenance. It was originally defined as a systems approach to pavement design [9-10].
There are several PMSs to choose from, each with a different level of sophistication. A modest system based on visual examination and stored in a Microsoft Excel or Access database might be sufficient for a small town or rural county. As a rule of thumb, a state road network can benefit from a more complex PMS [11-13]. Where instructions on how to carry out compensating methods as a cost-effective alternative to rehabilitation were supplied. The aim of this review is to look for or investigate the PMS and how to appropriately implement this system by selecting the suitable treatment at the optimal time for the correct pavements in order to extend the life of such roads at a cost that is reasonable.

2. The components of PMS

The majority of formal definitions of a PMS agree on five essential components:

- Surveys of pavement condition. Improving measurement and data collection is the major focus of condition survey studies. In the United States, transportation agencies probably initially used pavement condition assessments as part of the PMS. For instance, in 1965, WSDOT initiated pavement studies as an early adopter of PMS.
- A database storing all pavement-related information. The data from pavement condition surveys that databases are intended to store have developed along with them. In the 1970s, when sufficient, affordable computing power and storage became accessible, computer databases became more common. Better user interfaces, especially GIS-based spatial interfaces, and stronger databases have been the focus of recent research (such as Microsoft SQL Server, Oracle, and others). These interfaces provide meaning to the facts.
- Analysis scheme. The algorithms used to evaluate data in meaningful ways are referred to as analysis schemes. The emergence of computer-based optimization methods occurred in the late 1960s and early 1970s. The database, analytical plan, and decision criteria may all be combined into one package using modern software. Recent studies have concentrated on developing or improving performance prediction, optimization methods, and life-cycle costing analyses.
- Decision criteria. The guidelines created to direct pavement management choices are known as decision criteria. Decision criteria have advanced along with pavement management systems and now consider factors including user delay, vehicle running expenses, and, in rare instances, environmental implications. The capacity to automatically apply suitable choice criteria and to build and improve these criteria is still being researched.
- Implementation procedures. The techniques used to apply management decisions to individual road segments are known as implementation processes. Implementation is not frequently covered in research since it is frequently viewed as a political, financial, or procedural issue.

2.1. Influencing factors on the performance of a pavement

2.1.1. Traffic

The greatest significant influence on pavement performance is traffic. The amplitude, configuration, and load repetitions of heavy vehicles have the greatest impact on the pavement performance. The damage generated by an axle per pass on a pavement is measured relative to the damage caused by a normal axle load(E80), which is specified as 80 KN. Consequently, a pavement is built to sustain a predetermined number of (E80’s) (or standard axle load repetitions) before deteriorating [14-16].

2.1.2. Moisture (water)

When natural gravel materials, particularly the subgrade, are exposed to moisture, their support strength significantly decreases. Moisture can enter the pavement structure via surface fissures and holes, lateral subgrade penetration, and capillary action from the subsurface water table. Moisture penetration lubricates particles, displaces particles, and causes pavement collapse. SUBGRADE, if the subgrade isn't strong enough to hold the weight of the wheels, the pavement will bend too much and fall apart. If the design of the pavement doesn't take into account differences in the subgrade, the performance of the pavement will vary a lot [14-18].

2.1.3. Construction quality

Inadequate compaction, poor moisture conditions during construction, poor material quality, and accurate layer thickness (after compaction) all have a direct impact on pavement performance. These specifications emphasis the importance of competent workers as well as improved inspection and quality control systems throughout the building process [14, 19].

2.1.4. Maintenance

What, when, and how maintenance is performed determines the pavement's performance. The pavement will deteriorate over time regardless of how well it is built. Maintenance must be performed promptly; if a road is allowed to degrade to a very poor state, the cost of restoring it may be four times that of fixing it early. By delaying maintenance, four more roads would need to be repaired, increasing the expense of rehabilitation by a factor of 16 over a few years. Delaying maintenance also has this effect. For this reason, putting off maintenance due to a lack of funds will have serious consequences in a few years’ time [14].

2.2 Functions of the PMS

To put it another way, pavement management will make it easier for top management, pavement engineers, and other stakeholders to make decisions that are efficient financially about the "what," "where," and "when" of pavement care and rehabilitation. When should treatments be planned, where should they be performed, and what is the most cost-effective treatment? [20]. Regardless of the size, organizational mix, and available resources of any adopting agency, pavement management systems should accomplish the following tasks [21]:

- Improve decision-making efficacy in pavement management operations.
- Increase the breadth of the pavement management procedure by including pertinent data in the decision-making procedure.
- Provide feedback about the outcomes of future decisions,
- Promote collaboration, coordination, and dialogue among agency staff members involved in pavement management.
- Ensure that choices made at various management levels within the same company are consistent.

2.3 The advantages of PMS

An organization may get benefits by introducing a PMS. There is a long and well-documented history of effective and helpful PMS implementations. Even though it can be hard to calculate the direct economic benefits of setting up a PMS, one benefit that must be considered is being able to choose the most cost-effective ways to repair and maintain pavement. This advantage provides the most efficient use of an agency's available cash [21-22]. Aside from immediate economic benefits, a PMS has several additional possible applications, including [21]:

- More precise and easily available information on the pavement network.
- Assessment of the pavement network's condition must be quantified.
- Capability to monitor the efficacy of certain treatment techniques.
- Determine the requirements for future activities and spending budgets.
- Encourage state legislators to appropriate greater funds for pavement maintenance and restoration efforts.
- Justify and defend project prioritizing decisions when engaging with local lawmakers or the general public.
- Enhance credibility when interacting with the transportation agency's senior executives.
- Serve as a foundation for dividing funding across various districts or agencies.
- Assist in selecting the optimal repair measures or tactics for various pavement management sections.

Because of traffic and environmental conditions, all pavements deteriorate with time. Pavement management processes are focused on finding the best cost-effective combination of treatment options to apply to a specific pavement segment at any given time in order to maintain or achieve a specified level of serviceability [21].

3. Pavement maintenance management system (PMMS): principles and concepts

The pavement management and maintenance system can be defined as a set of procedures and tools that the responsible authorities can use or follow in order to assist decision-makers in adopting the best strategies possible in light of the current pavement conditions. This is done by conducting an evaluation and maintenance of the pavement with the goal of extending its acceptable service for the necessary duration of time. It depends on visual inspection, one of the simplest methods for assessing small towns' rural route networks [23]. An automated monitoring system is appropriate in only certain conditions for urban road networks in big cities. Because of its fundamental requirements, this type of PMMS requires a large amount of data to be stored in its database and later processed into information. In order to make decisions, provide support, and plan, it will require information after processing. The framework for this system's operation is shown in figure 1. [24].

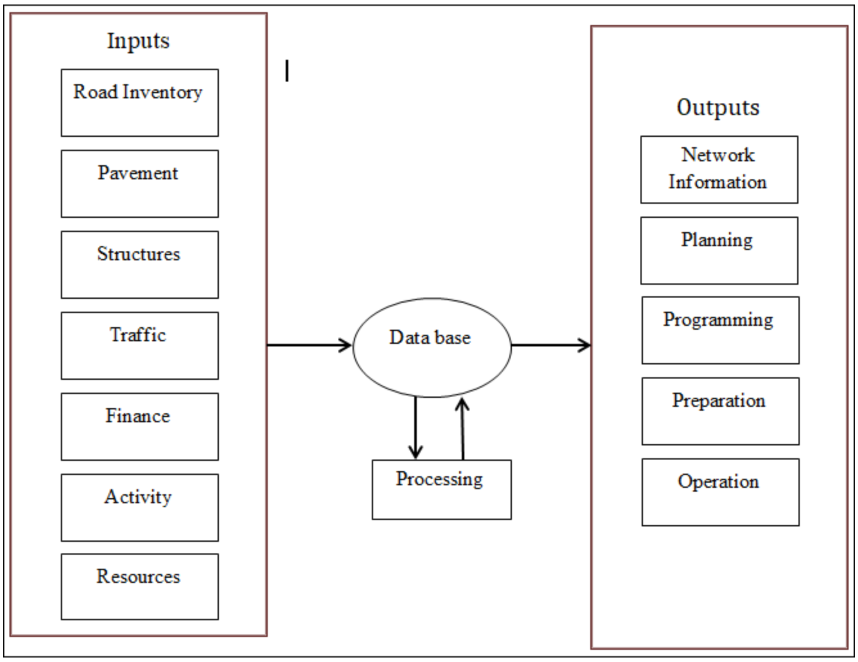

Fig. 1: The structure of the application system [24].

4. A guide for PMMS using the deterioration model

As illustrated in figure 2, an evaluation of the deterioration of the pavement during its service life and the costs associated with treating it can be made [24]. The vertical axis in figure 2 indicates the pavement condition index (PCI), which is scaled from 0 to 100; when the pavement is in excellent condition, it receives 100, but when the road entirely fails, it gets 0. Whereas, the horizontal axis represents the pavement's age. After approximately 70% of its life (usually 20 years), the pavement deteriorates to a bad state. As seen on the curve, the treatment alters as the pavement condition deteriorates, resulting in greater treatment costs. It will be able to keep prices low and treat more roads if it will appropriately time the treatments, especially when the road condition is in the upper 70% of the curve then the cost of repair may be higher than the construction. As illustrated in figure 3, if the pavement is not treated in a timely manner, the level of service will quickly drop, and the relative costs of maintenance will rise. Theoretically, flexible pavement works well for the duration of its design before deteriorating due to the oxidation of the asphalt over time, which leads to issues with the roads and subsequently a decline in performance [24].
The type of materials used to build the pavement, the environment, the loads imposed on those pavements, and maintenance intervals are the number of the variables that affect how long the pavement will stay in good condition. figure 4 depicts the pavement's major rehabilitation process. As the pavement starts to deteriorate even more is when this happens[24].
The preparation of plans for the maintenance and repair of these pavements will be made easier by subjecting the flexible pavements to a monitoring system based on the PMMS program once they are opened to traffic. Within a pavement network, there are many different pavement deterioration curve shapes and ideal maintenance and repair points. From a technical perspective, guidelines for diagnosing distress can help in determining the type of distress and offer potential maintenance treatments [24-26]. As seen in figure 5, various researchers have proposed a particular scale for classifying pavements [27-29].

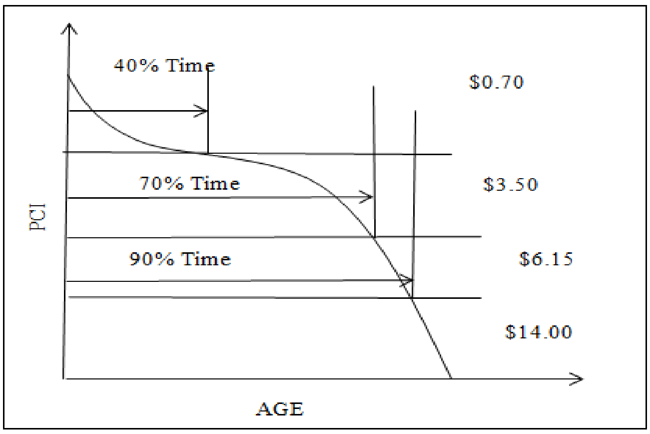

Fig. 2: Costs of repair and the impact of treatment time [24].

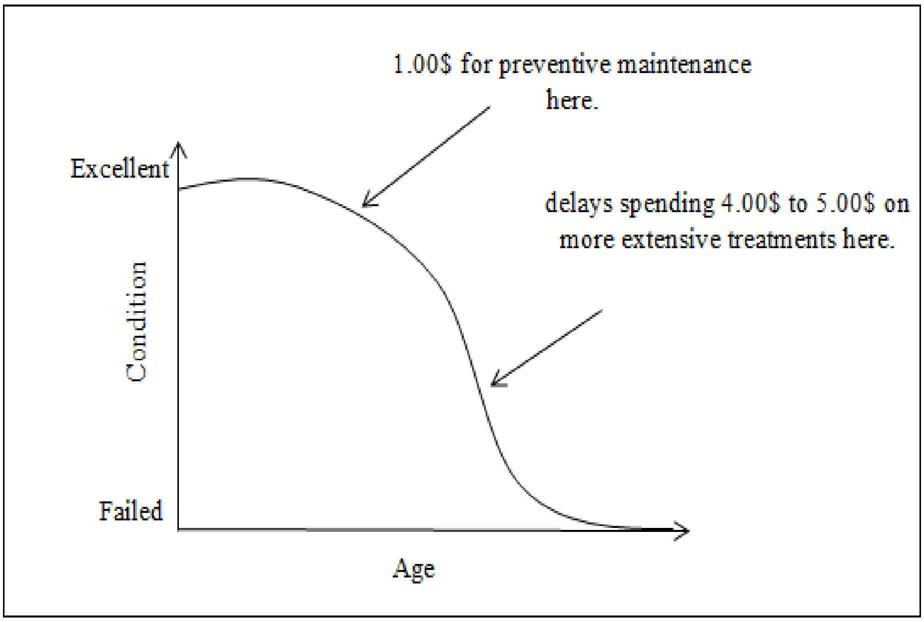

Fig. 3: Life of the pavement and maintenance costs [24].

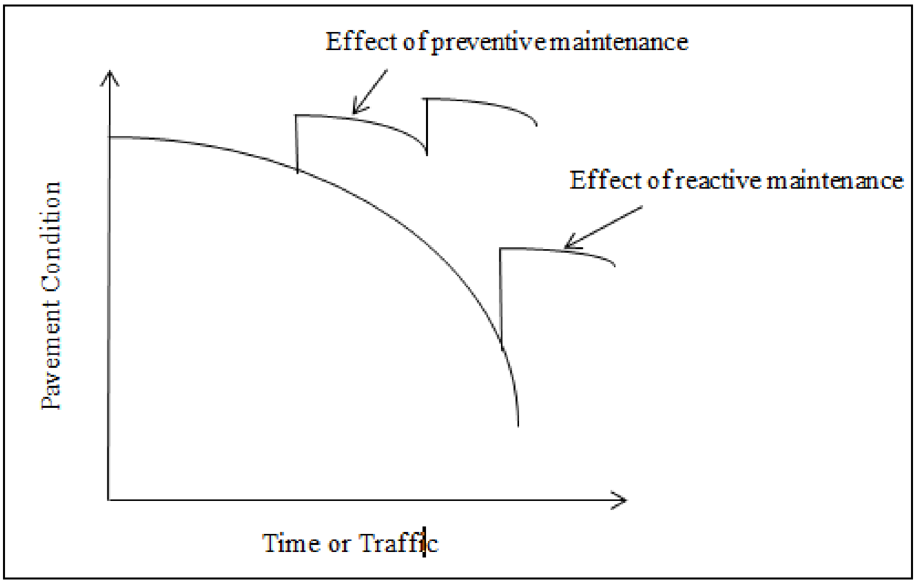

Fig 4: Maintenance strategies [24].

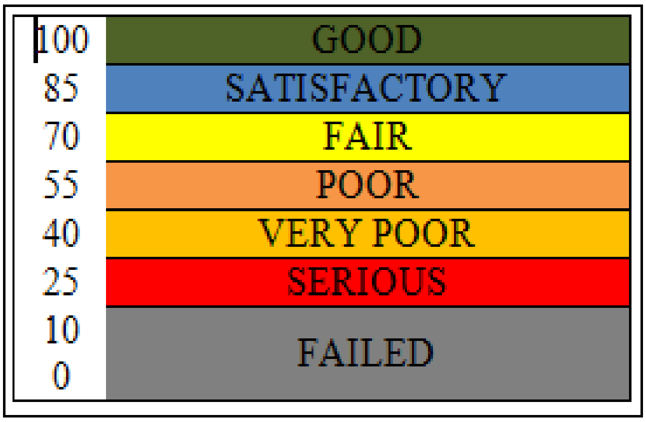

Fig 5: Scale for Rating Pavements [24].

5. Evolutionary innovations and developments

According to a historical view of the growth of pavement maintenance, this is primarily attributable to ongoing advances and innovations. While several particular examples might be given, here are a few yet-to-complete highlights [30]:

- Since the 1970s, there has been a comprehensive framework in place that covers planning and priority programming, in-service monitoring and evaluation, the design of new pavements, the preservation and rehabilitation of existing pavements, as well as construction and maintenance.
- The availability of performance data online, as well as the development of high-speed, automated procedures, tools, and equipment for pavement monitoring and data gathering.
- Integrating pavement management, a major component system, into broad-based asset management at the strategic, network/system-wide, and project/site-specific levels and identifying asset value as a crucial component.
- Life-cycle analysis is frequently used in pavement design and maintenance.
- The need of both routine and emergency pavement repairs has been acknowledged.
- Increasing use of P3 contracts, which are based on long-term performance, around the globe.
- Background knowledge was supplied by the LTPP and MEPDG investigations.

The following are some of the fundamental elements driving this evolution [31]:

- The PMS is integrated into the wider framework for asset management.
- Organizational commitment at all levels
- At all application levels, the ability to serve users swiftly and consistently.
- Understanding the underlying technologies and limitations of the PMS.
- A solid, dependable, and up-to-date database.
- Consider succession planning not only for people but also for technology and information.
- Sufficient resources, particularly financial resources.

6. PMS for the future

Pavement management has grown into a commonly used procedure all around the world. However, new developments are always needed, and they must be used consistently since they form an essential part of road asset management. Dedication, technological, economic, and institutional progress, and sufficient resources are essential to making this vision a reality [29]. There are other claims that the ideal PMS of the future will include the following characteristics:

- Efficient deployment at all levels and easy connection with larger asset management systems.
- Maintaining open lines of communication with internal and external stakeholders.
- The PMS is outlined in detail in the company's business strategy, and those benefits have been thoroughly researched.
- Providing resources to maintain the PMS's dynamic nature.
- Leadership that is dedicated to excellence
- Agencies at all levels must support the policy objectives, performance metrics, and execution.
- A large, dependable long-term database
- An inherent "culture" of invention and progress.
- A group of researchers and practitioners who are skilled and knowledgeable.

7. Conclusion

1. Over the last decades, many innovations and changes have been made regarding PMS, but with the current world demand for transportation facilities (Highways), more needs to be done.
2. Transportation facilities are among the major indices of development of any society. Therefore, more investments are required from academia (researchers) and public and private organizations to ensure their good maintenance and judicious use. Therefore, the importance of Pavement Management should be emphasized. This is due to the importance of maintenance schedule.
3. If the pavement is allowed to deteriorate to a very bad condition, the cost of repairing the route will be significantly greater than the cost of rebuilding the road at the initial level.

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