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Pavement Management in Highway Engineering

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Abstract Since its construction, periodic maintenance has been necessary to keep the original pavement serviceable. Because both works and findings had to be estimated and scheduled, this was the first sort of pavement management. Later, the introduction of engine vehicles resulted in a significant increase in travel speed, necessitating the creation of safer and more sturdy pavements. In this research, we will investigate the notion of preventative maintenance, selecting utmost cost-effective maintenance treatment, maintenance materials, and maintenance treatments for both asphalt and concrete pavements. Pavement management encompasses the many components and duties necessary to maintain a high-quality pavement inventory while also ensuring that the overall condition of the road network is kept at a high level. A pavement management system (PMS) is a decision-making system for pavement management. PMS software solutions predict future pavement damage caused by road traffic and weather and prescribe road pavement maintenance depending on the kind and age of the pavement as well as many metrics of present pavement condition. According to studies, it is significantly less expensive to maintain a road than it is to restore it once it has been damaged. As a result, pavement management systems prioritize preventive maintenance of excellent roads over road reconstruction of inferior roads. As a result, system performance will increase in terms of lifetime cost and long-term pavement conditions. The author used the approach to construct PMSs at the project level, which was helped by pavement condition evaluations.

Keywords Pavement Management, Maintenance, Materials, Treatment

1. Introduction

The act of planning and repairing roadways or other paved infrastructure to maximize pavement conditions over the entire system is referred to as pavement management. It is utilized in places like airport runways and marine freight docks. Every highway supervisor oversees the pavement in some fashion. Through pavement management, service life costs are included into a more methodical approach to minor and large road maintenance and rebuilding projects. Before undertaking projects, the needs of the whole network, as well as budget estimations, are examined, because the cost of data collection might vary substantially.

Pavement management comprises the several components and responsibilities required to preserve a high-quality pavement inventory and ensure that the general condition of the road network is maintained at a high level. While pavement management encompasses the whole lifetime of pavement in any transport infrastructure, from planning to maintenance, road asset management and road maintenance planning are mainly focused on road infrastructure [3].

Figure 1 depicts the elements of a project management system. A visual condition survey, coring, and the use of relevant technologies evaluating surface characteristics like skid resistance and transverse/longitudinal evenness are commonly used to evaluate the functional state of the pavement.

Figure 1. Pavement Management

2. Terms and Definitions [1]

Pavement management is described as "the effective and efficient direction of the numerous tasks involved in delivering and maintaining pavements in a state acceptable to the traveling public at the least life cycle cost." Pavement management may be defined as the practice of planning maintenance and repair activities to maximize pavement conditions. The creation of the pavement management system was prompted by the need for pavement management (PMS). PMS is a pavement management tool. It may be identified as the systematic and coordinated management of the operations involved in pavement management [7].

PMS is defined as a set of tools or methodologies that help decision makers in figuring out the best strategies for delivering, assessing, and keeping functional pavements throughout time. Some agencies use the term pavement management program (PMP) in addition to PMS. PMP has the same structure and is comparable to PMS, however the financial factor at the stage of job choice and programming may be considered more important (budget predictions, source allocation, etc.) [23].

PMP may be described as a decision-making tool that offers extensive network/project records, pavement condition records, maintenance history records, maintenance / rehabilitation strategy determination, and long-term budget estimates and source allocations. PMP is vitally necessary for consortia executing highway construction under concession agreements since they must manage the pavement in the most effective manner while delivering proper and safe services [14].

In general, pavement management looks to manage pavement maintenance and repair in the most cost-effective manner possible. This is accomplished by combining low-cost treatments on excellent pavements with more expensive treatments on badly degraded pavements.

Finally, a PMP might be manual or automated. Computerized PMSs can handle and analyze vast records resulting from functional and structural pavement studies more quickly, and the majority can anticipate future pavement problems. The fundamentals for establishing such systems or programs are the same whether the network is rural or urban.

3. Importance of the Pavement Management [1]

- Additional reasons have contributed to the need for a more methodical approach to pavement repair work:
- The rapid expansion of the road network, its aging, and the necessity to maintain a suitable degree of safety and functioning.
- An increase in maintenance costs, as well as the difficulty in finding funding for repairs when it is required.
- Recognizing that the state of the pavement has a direct impact on social activities and the environment.
- The development of novel pavement maintenance procedures and materials.
- The critical necessity for energy conservation.
- The need to reuse construction materials to save natural resources.
- Acceptance that pavement condition influences user cost.
- The creation of equipment that allows for the objective and rapid assessment of pavement condition.
- The advancement of computer and software development; and

- The realization of the deployment of management tools and techniques in pavement engineering.

Pavement management is implementing the ideal solution at the most suitable moment, using the most acceptable materials and maintenance methods and procedures, with the goal of achieving the lowest feasible maintenance cost and a longer service life for pavements. Pavement management refers to the secondary capital required for maintenance after the primary capital has been spent on construction.

4. Pavement Management Systems [4]

A pavement management system (PMS) is a pavement management decision-making system. PMS software systems predict future pavement damage due to road traffic and weather and recommend servicing to the road's pavement based on the kind and age of the pavement as well as several metrics of current pavement quality [4]. Measurements can be obtained on the ground, visually from a moving vehicle, or through automated sensors attached to a vehicle. PMS software typically supports users in establishing composite pavement quality scores for highways or road segments based on pavement quality parameters. Recommendations are often focused on preventive maintenance rather than allowing a road to deteriorate to the extent where it requires more extensive rehabilitation. Figure 2 depicts the components found at the network level.

Pavement management systems typically carry out the following tasks:

- Inventory pavement conditions, recognizing good, fair, and bad pavements.
- Determine the relevance of road segments based on traffic quantities, road functional class, and community demand.
- Maintain decent roads on a regular basis to keep them of satisfactory quality. [5]
- Schedule repairs to bad and fair pavements when funds become accessible [6].

According to research, keeping a road is far less expensive than restoring it once it has been damaged. As a result, pavement management systems favor preventative maintenance of outstanding roads over road reconstruction of poor roads. As a result, system performance in terms of lifetime cost and long-term pavement conditions will improve. Agencies that focus on repairing their problematic roads may find that after the time they've repaired them all, the good roads have deteriorated [6].

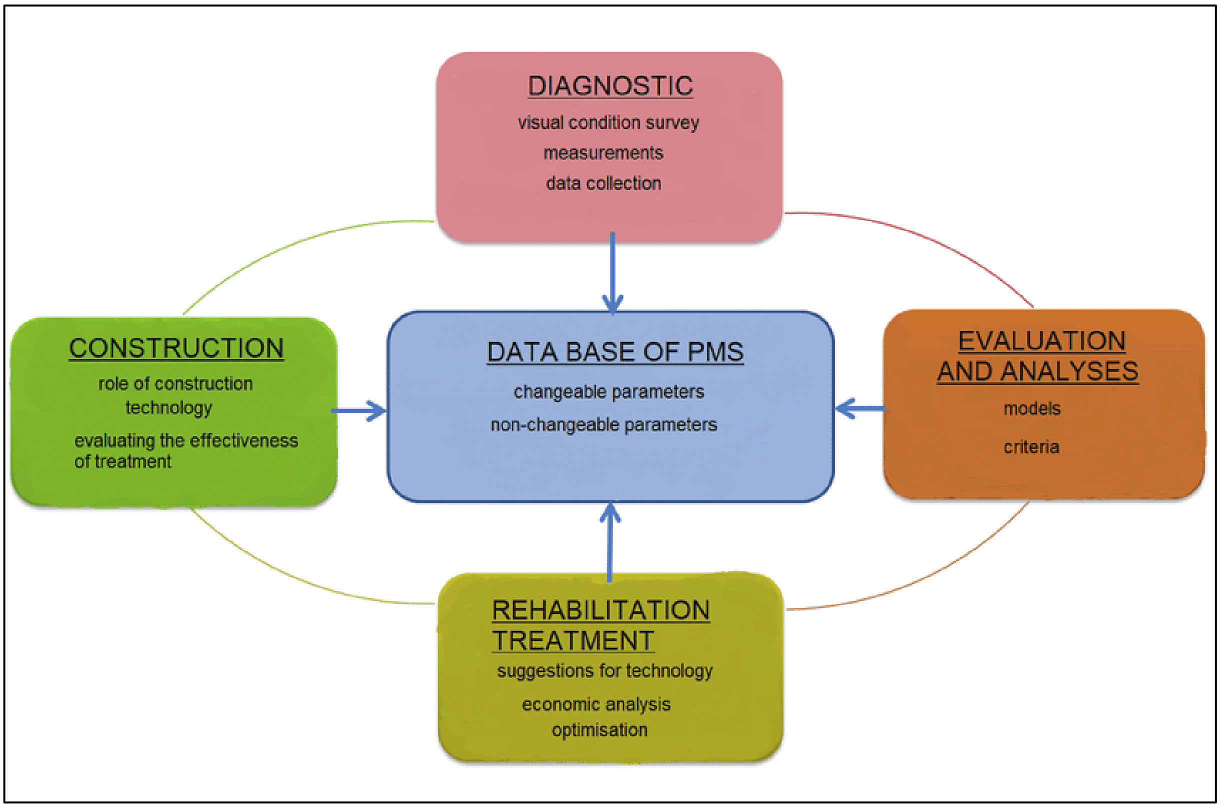

Figure 2. Framework of Pavement Management

5. Purpose of Pavement Management [5]

The purpose of pavement management is to get financial, technical, organizational, and administrative benefits:

5.1. Financial Benefits

Pavement management should strive to perfect net financial gains in respect to financial constraints. This is accomplished by doing the following:

a. Effective management of available finances.
b. Planning maintenance/rehabilitation projects in line with available budget.
c. Calculation of the impact of various maintenance/rehabilitation alternative options on the cost of the proprietor and the user.
d. Assessment of the influence of building quality on user costs.
e. Aim assessment/selection of the best option based only on cost/benefit analysis.

5.2. Technical Benefits

Pavement management should supply technological advantages. To obtain technological benefits, a PMS should:

a) Have a large and integrated database (data bank) that is continually updated.
b) Be reformed utilizing experience and current technical breakthroughs, by improving maintenance and building processes and avoiding the same faults.
c) Select the best technique of maintenance/rehabilitation.
d) Use trustworthy pavement behavior forecast models as well as cost/benefit estimation methods.
e) Use decision-making criteria such as desired level of pavement condition, warning level, and intervention level.

5.3. Organizational Benefits [7]

There should be organizational advantages in pavement management; to achieve this, a PMS should be able to:

a) Fairly figure out the pavement state at the network or project level.
b) Plan and schedule both current and future maintenance tasks.
c) Employ the most effective and efficient approach for systematic pavement
d) Condition monitoring.
e) Forecast the impact of various funding options.
f) Serve as an objective foundation for political choices.

6. Levels of Pavement Management Analysis

PMSs that are employed in decision making are classified into three reference levels: project, network, and strategic. The project-level PMS considers a specific segment (or segments) of the road network. The network-level PMS examines a large area's road network, such as a district or county. The strategic-level PMS considers the whole road network of an area, or even the entire country or state. Depending on the needs, some current integrated PMSs are designed to work at all levels [5,8,11].

7. Pavement Management at the Project Level

At the project level, pavement management entails choices on the maintenance and rehabilitation of individual pavement sections, which define the 'project'. Decisions are completed by operation engineers with strong technical backgrounds, and they are based on technical merit rather than resource requirements and budget estimates. A complete functional and structural assessment of the pavement sections is performed in a project-level PMS, and the reasons of degradation are shown, followed by the choice of the suitable solution (routine maintenance, maintenance, rehabilitation, or reconstruction).

Decisions are often based on the pace of deterioration of the pavement segment, which is supported by previous maintenance and construction data. When weighing various options, life cycle cost analysis is utilized. All project-level data is stored in a central data bank, which also contains data from other projects and the road network. A project management system, in particular:

a) Considers all fundamental pavement design factors such as subgrade strength, traffic volume, material attributes, climatic circumstances, material cost, pavement age, and remaining life.
b) Performs extensive pavement analysis.
c) Determines the source of each discomfort and recommends correction measures or alternative options.
d) Uses life cycle cost analysis when considering alternatives.
e) Determines and prioritizes whether each particular pavement segment will need maintenance, rehabilitation, or rebuilding.
f) Determines the materials to be used and the rehabilitation thickness.
g) In tabular or graphical form, presents pavement condition, results, and suggestions.

h) Provides inventory data, pavement characteristics, pavement behavior, and remedial steps implemented in individual project portions to the main data bank. As an example, Figure 3 shows the elements of PMS at the project level.

8. Pavement Management at the Network Level

Pavement management at the network level deals with summary information about the network in question, with the goal of prioritizing maintenance and rehabilitation works based on the amount of financing available. Senior executives make the decisions. According to the Asphalt Institute, they make choices that influence defining pavement performance objectives, allocating cash to regions or districts, and developing pavement preservation plans. Traffic speed moving devices evaluate the functional and structural integrity of network pavements; restricted coring and falling weight deflectometer (FWD) tests are performed solely to corroborate moving device findings and acquire additional structural data on pavement layers at selective locations.

A network-level PMS:

a) Shows the current pavement state of the network.
b) Forecasts and predicts future requirements
c) Identifies potential initiatives for enhancements.
d) The shortlisted projects' priorities
e) Establishes budgetary requirements for both short- and long-term demands.
f) Estimates the impact of alternative fund investments on pavement behavior in the future.
g) Establishes the final work plan, typically through an iterative process that involves relocating nearby tasks from one year to the next or combining related operations to generate economies of scale.
h) Displays network pavement conditions on a map and in tabular form.
i) Provides all data bought from the network as well as final decisions on remedial steps to the main data bank. Figure 4 writes down the elements of PMS at the network level.

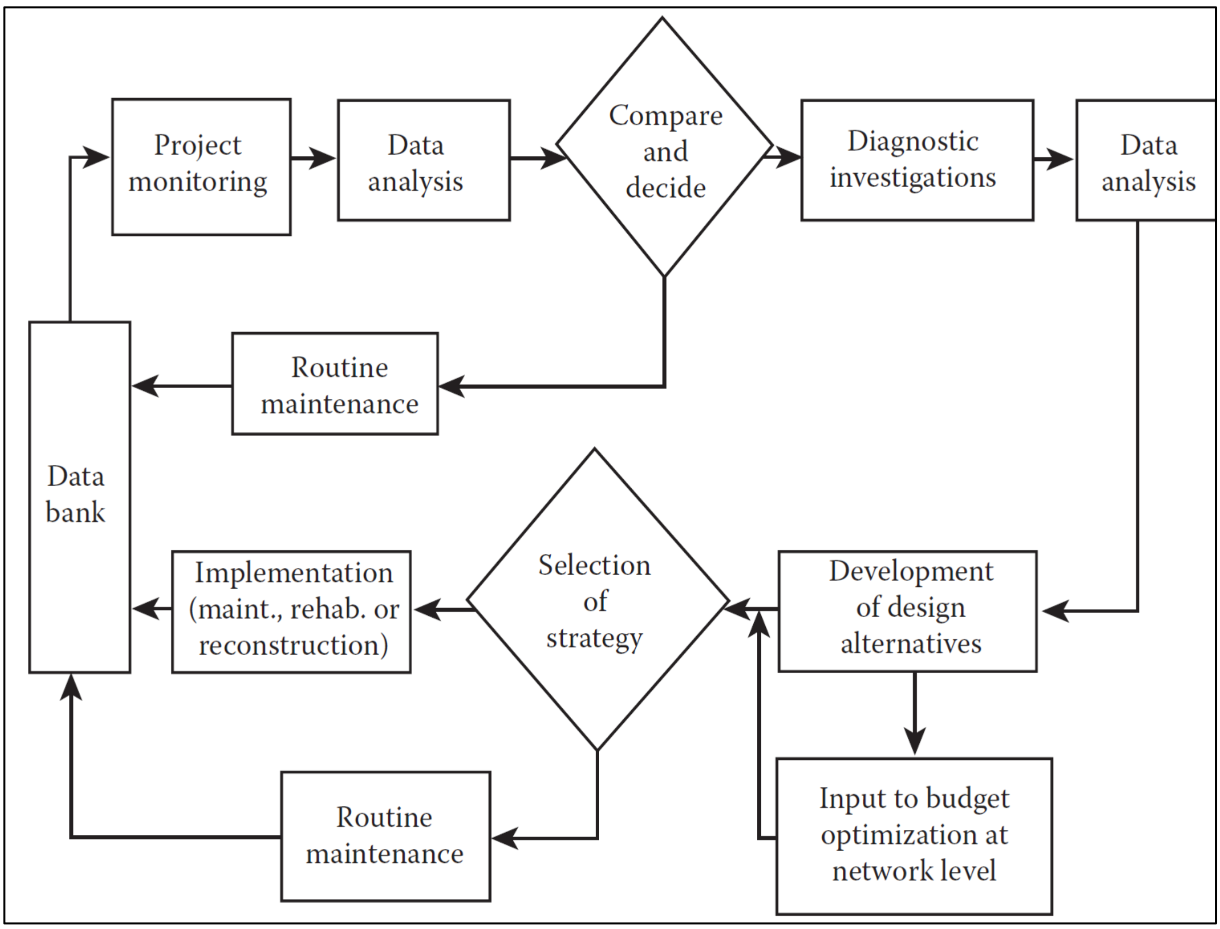

Figure 3. Elements of PMS at the project level [15]

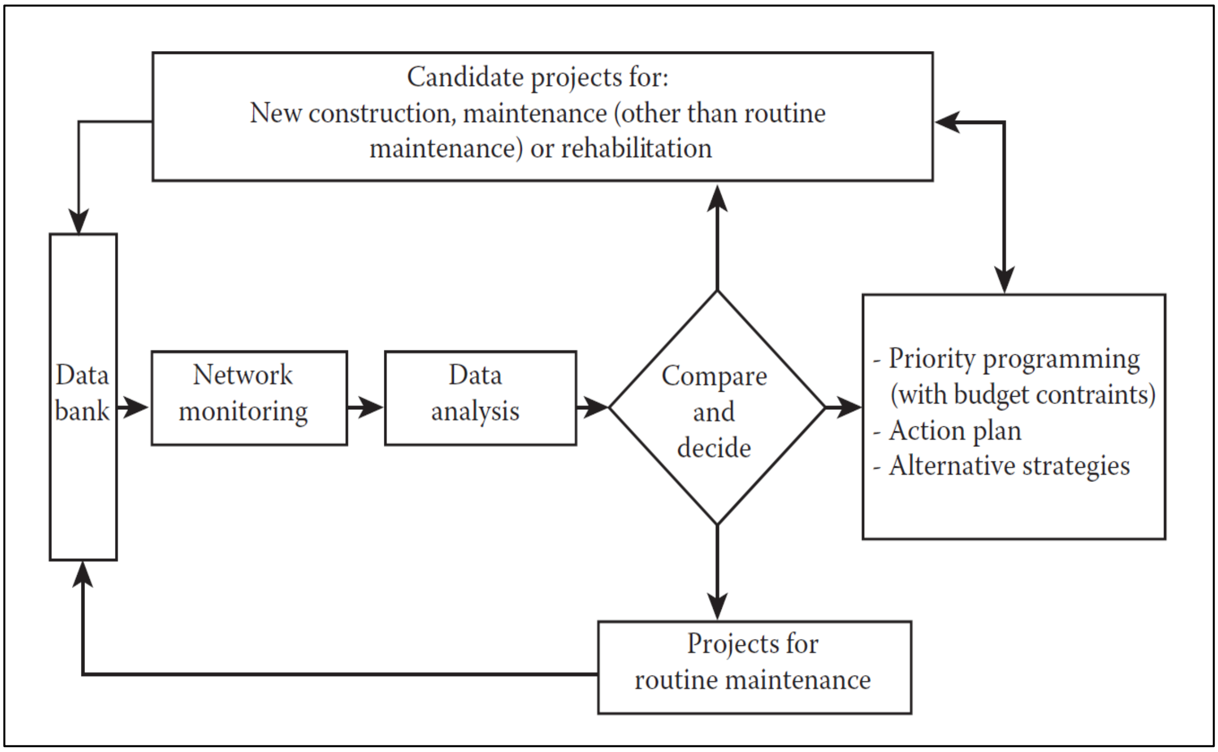

Figure 4. Elements of PMS at the network level [15]

9. Pavement Management at the Strategic Level [10]

Pavement management is currently employed in strategic choices made by government authorities, transportation boards, local councils, or top management of an institution. All are tasked with making long-term decisions based on pavement performance objectives, funding requirements to meet those standards, funding allocation among regions or districts, and pavement preservation policies. Strategic choices have traditionally been less organized than other levels of decision making, and the information on which judgments are based is more speculative, necessitating the capacity to forecast future events under several scenarios. Political interests may dominate in the lack of trustworthy information to serve as the foundation for solid business decisions [22].

10. Pavement Management Components [10]

A PMS is made up of the following components, independent of analysis level:

a) Pavement inventory.
b) Information on pavement conditions (survey).
c) Traffic information.
d) Post-Works History
e) Database.
f) The analysis module.
g) The reporting module.

Figure 5 depicts the interrelationship between the components [3].

11. Pavement Inventory

The pavement inventory is helpful and instructive, but it is important for pavement maintenance. The following are the minimal pavement features that must be recorded:

- Information about jurisdiction, such as concessionaire, district, area, or city.
- Location information, including the start and finish points of each pavement segment.
- Route categorization, such as highway, primary, secondary, or arterial road, crossroad, or interchange, among others. Branch identification is a word that is frequently used. A branch is a separate component of the pavement network that serves a specific purpose.
- The kind of pavement and shoulder (when it exists).
- The parameters of the road (branch), such as length, breadth, and number of lanes, as well as the width of shoulders (if they exist), and so on.
- Historical construction data, such as year/month of construction, one stage or planned stage construction, maintenance/rehabilitation history, materials utilized, layer thickness, bearing capacity of formation layer material, and anything else deemed relevant.
- Earlier traffic data.

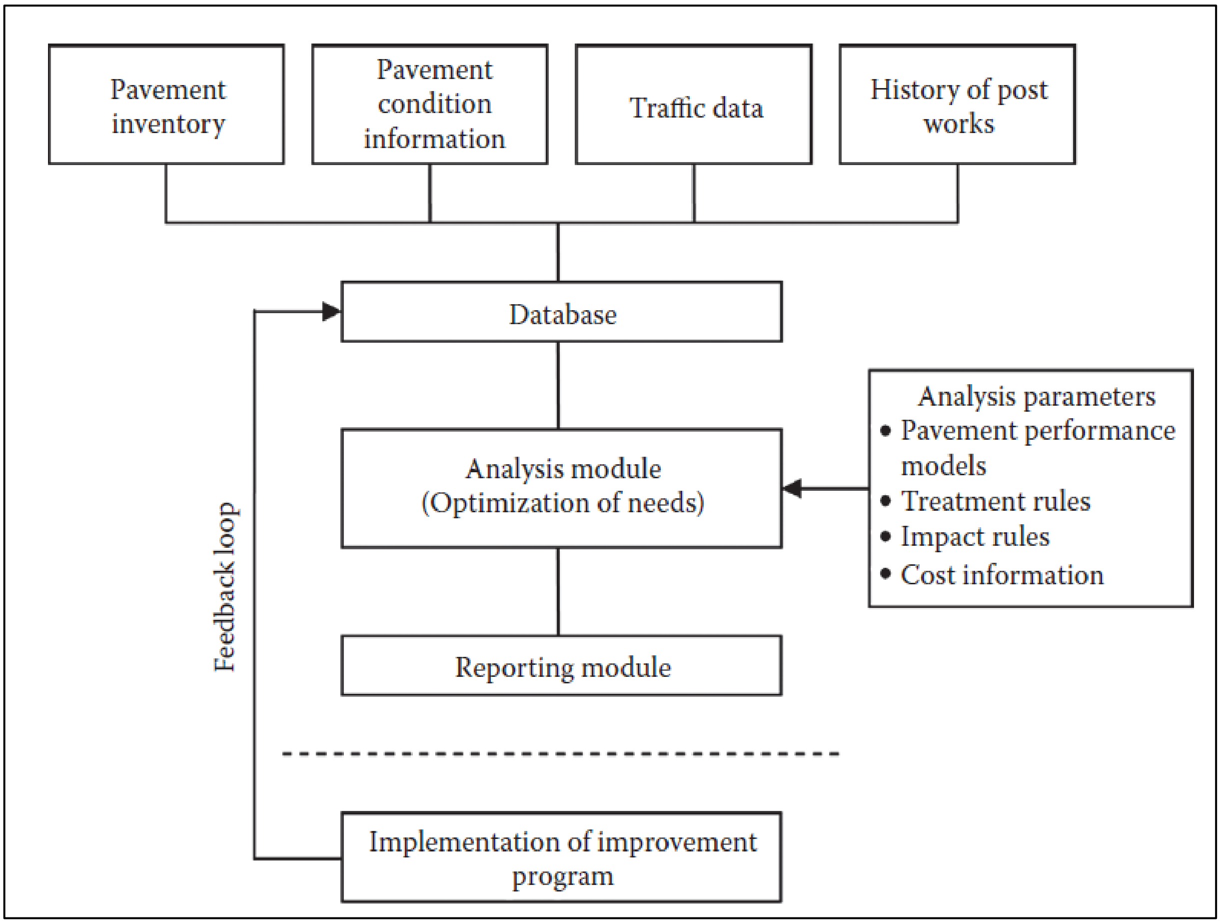

Figure 5. Basic pavement management components

Additional data such as bridge or underpass locations, road marking, streetlights, safety barriers, street furniture in general, accident records, construction, maintenance, rehabilitation cost, contracting companies' data, noise and air pollution measurements, and anything else related to the road may be included in the inventory.

Of course, the above-mentioned supporting data are not all required for a pavement management study. They are important, though, since they offer a comprehensive image of the route. The presence of all the features completes the data bank and allows for further road management decisions to be made.

12. Traffic Data

Historic traffic statistics and traffic counts are also essential for deciding earlier traffic and predicting future pavement conditions and remaining pavement life. Most countries have reasonably simple access to historical traffic statistics. If no data is available, previous traffic might be inferred based on traffic counts conducted during the surveying period, the average yearly growth in commercial vehicles since the date of construction or last intervention, and the number of years elapsed.

13. History of Post Works

The history of any post-construction work must be thoroughly documented. This is useful for calculating rates of degradation for locally existing problems. The variances in pavement performance are linked to pavement structure features based on initial construction details and the history of post-construction activities.

14. Database

A database should be utilized to maintain inventory, pavement condition, traffic, and history works data. Simple spreadsheets to a logical computerized database can be used to store data. The latter is preferable because it makes obtaining, organizing, and updating data quicker; it also enables access and the potential of remote sharing by all agency offices.

A database's location referencing system (LRS) and segmentation are essential features. Existing LRSs are virtually entirely linear and focused on highways or streets. A simple linear technique based on the mile post system is shown in Figure 6. The interchange numbering linear approach has also been used as shown in Figure 7.

The rise of global positioning systems and other spatial technologies causes the development of an LRS capable of accommodating and integrating data expressed in various dimensions [22]. More information on linear and multimodal LRSs is utilized in the United States. The display of database material may be done in a variety of methods, such as a:

(A) Text and tabular format (the most basic)
(B) Diagrammatic format (graphic representation of tables)
(C) Road profile layout (linear graphs showing information along the linear representation of the pavement).
(D) The network map format (specialized map drawings, may be GIS linked, showing pavement characteristic features).

The database's material should be displayed in a straightforward and understandable manner to the user. As a result, the majority of PMSs employ a mix of two or more data display types [19,20].

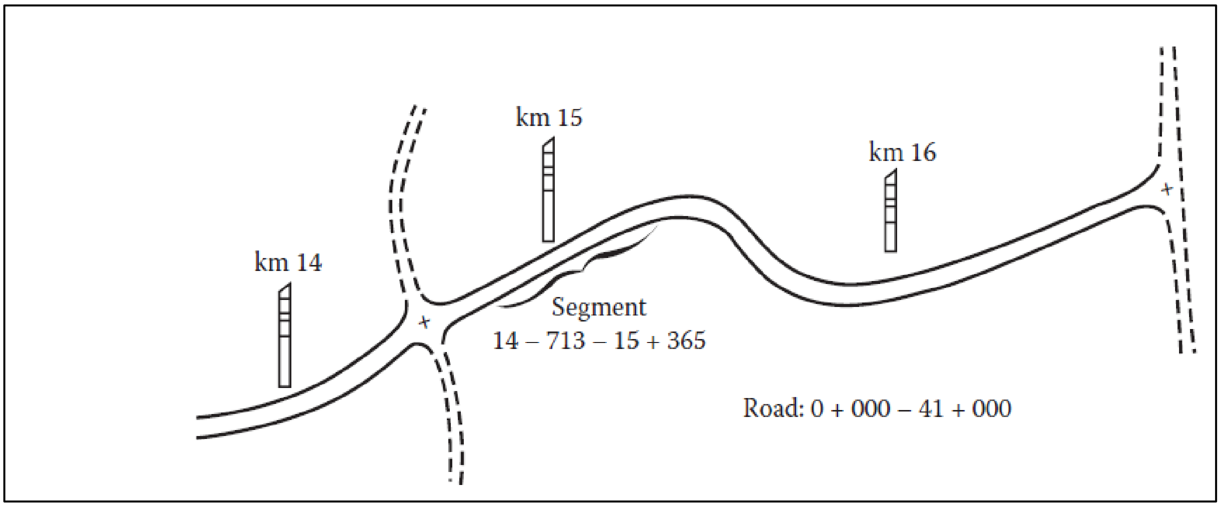

Figure 6. Linear LRS based on mile posts.

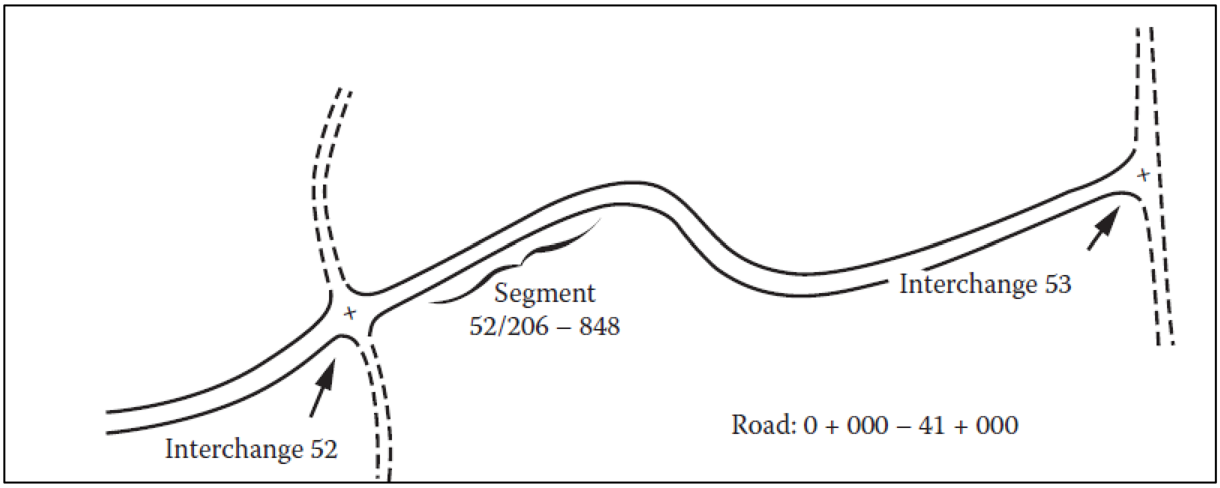

Figure 7. Linear LRS based on interchange numbering

15. Analysis Module [10]

The analysis module is the core of a PMS because, after processing and analyzing data, the maintenance/rehabilitation program is adjusted within given constraints, which are often budget constraints. Ranking and benefit/cost analysis may be used in both project-level and network-level optimization. However, the interface between project management and network administration is difficult to handle. Some parameters must be set to facilitate the analysis and prior optimization. The most frequent are pavement performance models, treatment guidelines, impact rules, and cost data.

Models of pavement performance Pavement performance or degradation models forecast future changes in pavement condition. They are crucial because they distinguish when maintenance/rehabilitation will be necessary, allowing future financial needs to be estimated. As a result, pavement performance prediction models must be as accurate as feasible.

The preceding is a difficult work since pavement performance is impacted by a variety of specific functional and structural pavement features such as evenness, rutting, cracking, raveling, potholing, skid resistance, and so on. Each of these features deteriorates differently based on the current conditions and kind of pavement, needing a unique treatment strategy [12].

To aid pavement maintenance, each pavement characteristic property should have its own unique degradation model, a virtually difficult undertaking. However, in 1969, the World Bank launched a study that grew into a large-scale joint research effort known as the Highway Design and Maintenance Standards Study (HDM Study), from which prediction models for all pavement distresses were developed and reported on the created prediction models, which were included into the HDM-III highway design and maintenance standards model [15]. Following the advent of the HDM-4 models, these models improved [16]. These distress models may be useful in pavement maintenance.

Although the national calibration-validation procedure for MEPDG in the United States was successfully completed (NCHRP 2004), the MEPDG advised additional calibration and validation studies in line with local conditions to increase the accuracy of MEPDG distress prediction models. Some of the assessment studies are already finished [18].

When appropriately built, a prediction model of the composite distress index PCI (pavement condition index) may also be employed in PMSs. The PCI prediction model created and included in the MicroPaver program is a successful example [21].

Finally, when FWD measurements are available from which the developed strains at the critical interlayer can be decided, fatigue equations derived in relation to the tensile stain of the asphalt or the vertical strain of the subgrade criteria can be used in PMS to predict the structural failure of the pavement, thus extending its life.

The author successfully employed the abovementioned technique, aided by pavement condition assessments, to create PMSs at the project level; one project was 112 km long, while another was 230 km long [13,14].

The remaining life calculated from FWD measurements corresponded well with the remaining life derived by back calculations utilizing the design nomographs of AUTH pavement design technique for flexible pavements in the same pavement management studies. The supply of precise previous traffic statistics is critical in this strategy.

16. Treatment Rules

Treatment rules must be developed to characterize the circumstances under which intervention works (maintenance, rehabilitation, or rebuilding) are deemed possible. The intricacy with which treatment guidelines are defined is defined by the agency.

The following are the treatment guidelines; Apply micro-surfacing to restore skid resistance if the pavement is in good condition and daily traffic is less than a specific level or apply asphalt concrete for very thin layers (25 to 30 mm) (AC-VTL). If the pavement is in good condition regardless of traffic volume, if the pavement is in good condition, mill and overlay with 40 mm hot mix asphalt (HMA) (dense asphalt concrete) and an AC-VTL wearing course, and if the pavement is in bad condition, mill and overlay with suitable thickness HMA and an AC-VTL wearing course.

Similarly, criteria for avoiding maintenance (crack filling, raveling, etc.), restoring longitudinal and transverse evenness (rutting), and so on can be defined.

17. Impact Rules

A PMS should include treatment selection impact rules. An impact rule specifies how much of an improvement in pavement quality may be projected from the application of a certain treatment, as well as how this treatment will perform over time. A treatment that will be used may restore the pavement's condition to good, which can endure for several years. Others may only postpone degradation for a limited time. The length or life expectancy of any therapy is crucial and may best be established from previous experience. To aid in decision making, the effect regulations must be considered in the cost analysis.

18. Cost Information

A PMS must include cost information since, in most circumstances, it is the deciding factor in treatment policy selection. Cost information might be as basic as a budget need for each year of the study period, or as a life cycle cost analysis for each alternative treatment solution or treatment category. The PMS may also supply amounts for materials and labor (e.g., tons of hot or cold mixtures, volume or area of milling, area of micro-surfacing, length of crack filling, area of patching or full replacement, length, or area of road marking, etc.). This option is more typically encountered in project-level PMSs.

19. Reporting Module

The findings of a pavement management study and the data in the database may be presented in a variety of ways, including text, tables, and graphics. To graphically display the information, several agencies connect their pavement management databases to geographic information systems (GISs) or other map packages. When communicating pavement problems to decision makers, GIS presentations of pavement management information are helpful tools.

A typical presentation of pavement management findings may be found in all relevant literature; some examples are provided in the AASHTO Pavement Management Guide. [21,22]

20. Implementation of Improvement Program

Following the final choice on the improvement program (preventive maintenance, maintenance, rehabilitation, or rebuilding), its execution follows. All completion dates, pavement condition changes, materials used, and other construction facts are supplied back into the PMS database. This will be useful information for future PMS upgrades.

21. Conclusion

Rising material costs have our framework's managers seeking new and more cost-effective methods to manage resources. With growing costs, the value of our installation supplies grows and becomes more expensive to maintain at a reasonable level of administration. Chiefs of these resources are recognizing a greater value in utilizing the executive's framework to keep up with their framework more likely in a cleverer approach. Asphalt normally deteriorates at a constant rate. The first couple of issues are accessible, and the pavement stays in reasonably good condition. However, as it ages, additional problems arise, making it easier for subsequent injury to occur. The two primary treatments used to extend pavement life are maintenance and repair.

In general, support can delay the rate of deterioration by repairing minor asphalt flaws before they worsen and cause more deformities. Abandons grows extremely large for modification by support after a certain point. Now, repair may be used to affect a cheap revision of several typically major flaws, so improving the pavement's state. Finally, a comfortable urban environment is important for people because it allows them to live a more active lifestyle, which gives them the opportunity to be healthier. Pavements should not be dirty; they should be pleasant to walk on, and this is one of the most important outcomes of pavement management.

Declaration

The authors have no conflict of interest with any aspect of this research.

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