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Empirical Models Investigation of Pavement Management for Advancing the Road's Planning Using Predictive Maintenance

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Abstract The current study is based on the empirical models of pavement management for advancing the road's planning using predictive maintenance. Pavement management is defined as the planning process to maintain and repair the roadway network and other road facilities for optimization of the conditions of pavement. Predictive maintenance on the other hand is referred to as the technique used to determine the conditions of the equipment to estimate the requirement involved in maintenance. The following study also discusses the challenges and strategies concerning pavement management using predictive maintenance. Challenges are connected to execution process, security and safety, over-maintenance and transmission costs while the strategies utilize the analysis of the historical data, identifying the critical assets, and installing the internet of things sensors. In addition, the relationship between pavement management and predictive maintenance is such that the road's planning and administration require the types of machinery and equipment to accurately manage the road that is highly necessary to maintain the equipment for efficient work. The study thus covers the objectives such as the concept and different types of pavement management, use of predictive maintenance, models of pavement management, challenges regarding developing the road's planning, and strategies for overcoming the challenges. Notably, interpretivism research philosophy and inductive research approach were applied in this study. Interestingly, only the qualitative type of data was used and was collected through secondary data collection; while conducting the thematic analysis as well. The discussion section of the study has found out the results and outcomes which prompt its importance in studying the models so that the proper framework can be used while conducting pavement management using predictive maintenance. Three types of pavement management were discovered which include pavement condition analysis, priority assessment models, and network optimization models. Their advantages are numerous which cannot be limited to detecting any type of anomalies in the operations, identification of every possible defect in the equipment, and maintaining downtime tracking software. More so, three models of pavement management namely; deterministic pavement deterioration model, probabilistic pavement deterioration model, and formulation of the distress indices were focused on in this study.

Keywords Pavement Management, Road Planning, Predictive Maintenance, Road Maintenance

1. Introduction

Pavement management is defined as the designing process to maintain and repair the roadway network and other road facilities for optimization of the conditions of pavement over the whole network. Predictive maintenance is referred to as the technique used to determine the conditions of the equipment for estimating the maintenance requirement. This makes use of condition-monitoring tools for monitoring the performance of the equipment and structure at the time of operations [1]. Herein, pavement management models were focused on in this study, namely, deterministic pavement deterioration model, probabilistic pavement deterioration model, and formulation of the distress indices. The following study also discusses the challenges and strategies of pavement management using predictive maintenance. The relationship between pavement management and predictive maintenance is such that the road's planning and administration requires the types of machinery and equipment to accurately manage the road that is highly necessary to maintain the equipment for efficient work, so that pavement management could not be hampered in any case. Therefore, predictive maintenance helps in programming the maintenance time of the equipment and roads [2]. The current study is highly significant because it provides in-depth knowledge and analysis of pavement management and predictive maintenance in road planning. It will help the construction industry to prevent issues in road maintenance and to keep it in a good condition as well as reconstructing the road results in long-term cost and time. This study will play a role in avoiding such problems by maintaining a better system performance [3].

The following study collected the data via a secondary research method and performed thematic analysis to find out the results of the entire study which thus brought about the aim and objectives as follows:

- To investigate the empirical models of pavement management for advancing the road's planning using predictive maintenance
- To understand the concept and types of pavement management used in the road's planning
- To determine the use of predictive maintenance for advancing the road's planning
- To examine the models of pavement management for evolving the road's planning with the help of predictive maintenance
- To identify the challenges regarding developing the road's planning related to pavement management and predictive maintenance
- To evaluate the strategies for overcoming the challenges associated with pavement management for progressing the road's planning using predictive maintenance

2. Literature Review

According to [4], a good asset management strategy depends on knowing and monitoring PIs (Point of Tangent Intersections) of roadways, particularly the physical PIs. Decision-makers may better plan corrective measures, boost customer satisfaction, and be proactive with budget planning and risk assessment by having a better grasp of PIs. Generally, pavement management takes life cycle costs into account when planning small and big road maintenance and rebuilding projects. Before initiatives are implemented, the demands of the whole network as well as budget estimates are considered since the cost of data collection might vary greatly [5]. Notably, planning the upkeep and repair of a network of roads or other paved facilities to maintain the best possible pavement conditions over the whole network is known as pavement management.

The growth of information technology (IT) has made planning maintenance much easier. Even if criteria have always been used to choose the target roads for repair, efficiency may be increased by using more advanced techniques. After a road is built, the Road Agency (RA), which is viewed here as any organization responsible for managing a road network, must pay ongoing maintenance expenditures [6]. Road maintenance is necessary to keep them usable and in good shape. Unmaintained sealed roads degrade and become impassable. For the planning of maintenance, information from the road network is required. The breadth of the plan is constrained by financial considerations, and the planning is defined or guided by assumptions.

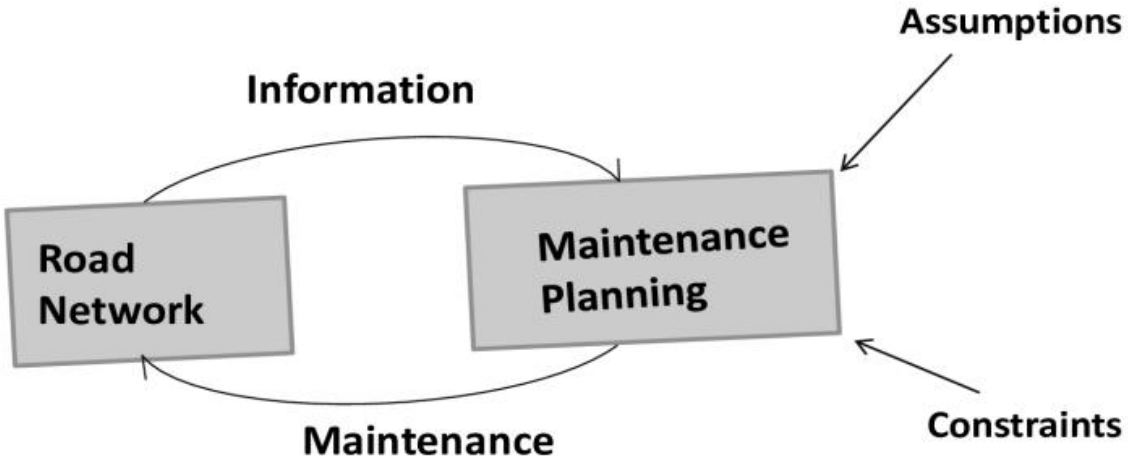

Figure 1. Advances in predictive maintenance planning of roads by empirical models, 2017

According to the viewpoint of [7], Road usage is related to broader areas of economic and social activities since roads make it possible for ground transportation. The maximum permitted speed and capacity of a road is determined by the requirements for road design, the materials used in construction, the environment, and the legal system. The goals established for the maintenance planning determine what data is gathered from the road network (Fig. 1).

Road location, geometry, and material decisions are determined during the design and building phases which cannot be significantly changed during the maintenance phase since the maintenance stage's goal are to extend the duration that the roads are useful while keeping them near the specified standards. Additionally, the two main components of RAP (Reclaimed Asphalt Pavement) are mineral aggregate and asphalt binder, and each of them adds trace chemical components from the perspective of [8]. Size-reduced samples are heated to dissolve them in an acid solution, and the resulting acid solution is thereafter analyzed for the presence of metals using a suitable tool, like inductively coupled plasma, optical/atomic emission spectroscopy (ICP-OES/AES), or atomic absorption spectroscopy.

The Pavement Management System (PMS) is a tool for making objective judgments that will maintain the pavements in good shape for the least amount of money.

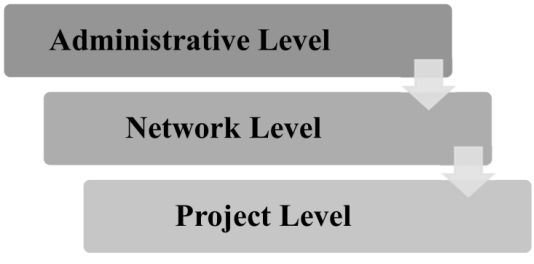

Figure 2. Decision Levels in Pavement Management System

At the administrative level, funds are distributed across several kinds of transportation assets. The objectives of network-level management often have something to do with budgeting. These objectives include identifying the maintenance, rehabilitation, and rebuilding needs, figuring out the financial requirements, predicting the future effects of different funding alternatives, and prioritizing the maintenance tasks for the chosen funding option [9]. The optimal plan for maintenance measures will be determined at the project level, along with specific maintenance and rehabilitation therapies. At each of these decision levels, pavement condition assessment is required for effective decision-making (Fig. 2). Over the years, several situation pointers for various pavement properties have been created.

Currently, the International Roughness Index (IRI), which rates the smoothness of roads and the comfort of riding on it, is perhaps the most standardized variable. IRI may be measured using a variety of techniques; the most popular uses an accelerometer or laser. The road surface is also important for texture, skid resistance, and roughness [1]. Macrotexture, Micro-texture, Skid Resistance Coefficient, and International Friction Index are among the indicators (IFI). The state of the sub-base and base layers, which cannot be immediately seen, determines the majority of the pavement's mechanical characteristics. A falling Weight Deflectometer can however assess the performance, or stiffness, of these layers (FWD).

Dynamic Cone Penetrometer may be used to assess pavement strength (DCP). Distress in the pavement may be caused by a failure in the mechanical qualities of the various pavement layers. The flexible road surface may show signs of raveling, weathering, rutting, alligator cracking, block cracking, and other types of pavement degradation. The visual examination has historically been used to gather data on these flaws since automated survey techniques weren't accessible [4]. Recent developments in data gathering and processing, however, have sparked

research and applications on automated Pavement Distress Inventory, such as the identification of cracking by image recognition and rutting by laser-based approaches. Roads are built to serve transportation demands, and design elements like the number of lanes and surface quality are often determined by traffic volumes.

Traffic amounts by vehicle classifications may be subdivided from the total traffic quantities. Traffic volumes take the form of time series, and the total volume is sometimes referred to as Annual Average Daily Traffic (AADT), which is calculated by continuously including all the cars that use a particular connection throughout a given year. Traffic is a major expense to society as a whole, in addition to impacting how quickly roads deteriorate [10]. Estimated network-wide traffic is needed for optimization in network-level maintenance planning. The resources needed for road maintenance include labor, money, expertise, and material. If the information is saved throughout the maintenance procedure, information about future maintenance needs may be inferred from the prior maintenance treatments.

Estimates of future maintenance costs are often made using historical maintenance costs derived from previous maintenance projects and adjusted for inflation. Multiplying the unit expenses by the number of units yields the real maintenance costs. In maintenance schemes, components are often capacity, part, or distance. If maintenance is carried out internally, it is possible to predict costs more accurately since the cost driver data is readily accessible [11]. High-temperature swings, changes in the temperature range between freezing and melting, as well as the quantity of rainfall has impacts on how effectively roads are managed and how quickly they deteriorate. In addition to recording air temperature, street climate stations may also be the best temperature of the highway itself.

In terms of road maintenance, there are two basic strategies: either currently existing damage is fixed, or attempts are made to avoid more damage. Numerous road maintenance projects might concentrate on a particular road layer, shoulder, or side drain. There are two types of maintenance tasks: regular maintenance and periodic maintenance. In addition to preventative maintenance procedures, emergency maintenance is performed when a significant fault prevents the road from being used efficiently [5]. Light maintenance tasks known as routine maintenance are conducted numerous times a year on the same section of the road. Small-scale and straightforward routine maintenance tasks are broadly scattered. Regular maintenance tasks include those that influence the surface course, such as filling up potholes and grooves for cemented paves and supple roadways, as well as those that affect the exterior of the surface course, such as vegetation management, road sign repair, and drainage clearance.

On the other hand, periodic maintenance refers to tasks often performed at regular but spaced-out periods in the same section. Resealing and overlaying are routine maintenance procedures for paved roads with flexible pavement [12]. Construction of rigid pavements and subsequent maintenance tasks are distinct from those for flexible pavements. Joint and blow closing, slab maintenance, repairing, rod bar retrofitting, physical hot mix tarmac overlaps, and physical PCC overlaps are all care responsibilities.

According to the perspective of [13], the time value of money for cost information should be considered by a discount factor since maintenance planning periods might last for many years or more. However, discount variables are difficult to predict since they change over time, thus using a predetermined yearly discount factor for the planning period is the standard practice. Although a defined discount factor may compromise the best use of allotted funds in multiannual maintenance planning, it does not affect the maintenance priority. Planning for road maintenance is hampered by practical concerns, mostly. These limitations mostly relate to the maintenance budget, contract conditions, and actual maintenance arrangements in practice [14]. In addition, the worldwide optimal asset management of road may require to be foregone in both public and private contexts, and a local finest need to be established within the parameters of the yearly budget restrictions.

The workers of the Road Authority might do internal road maintenance tasks or they can be outsourced to the private sector. Two primary contracting types for private sector maintenance: classic method-based contracts and more contemporary performance-based contracts. Planning for corrective repair on roads is different from planning for preventative maintenance. Failure kind and timing might be predicted [15]. In-person maintenance projects may be combined and conducted into maintenance packages in road maintenance planning from a variety of angles. Planning for road maintenance may be divided into several categories based on how long the plans will last. The planning time for medium-term maintenance is between one and ten years, whereas the planning period for long-term maintenance is longer.

According to the perspective of [16], to provide a reliable transportation system, there should be a need for service quality and safety as well as in the rising aviation industry. A complex system like an airport requires frequent checks to ensure that the norms and regulations set by national and international competent control agencies are being followed [9]. To meet the set goals, all facilities must operate efficiently. To guarantee the necessary level of service on the airside, a pavement management policy enables it to be certified by the national aviation authorities. The technology used to maintain airport pavements is called the Airport Pavement Management System (APMS).

It is a technique that helps in decision-making theoretically and frugally that includes techniques of sound management for conserving the best imaginable national of the airport asphalts for a convinced quantity of period

while following current legal needs. On the other side, the deployment of an APMS entails charges for inventory management procedures, database creation and upkeep, the creation or purchase of management software, and data analysis [17]. However, the advantages of APMS are widely acknowledged, and APMS practices are included in the airport handbook which help to keep the airport certified. Numerous physical qualities and/or status indicators would need to be considered and evaluated over time in a monitoring system how airport pavement reacts to traffic. The accepted APMS made use of a few high-performance measurement tools to reduce the number of people and cars in the detection surveys for a respectable amount of time.

As per the perspective of [18], the necessity of road maintenance is growing as the metropolitan road network expands, ensuring the effective functioning of the transportation infrastructure. The sophistication of road maintenance is greater than that of road building. Despite significant labor and financial investments, management divisions struggle with inadequate and tardy road maintenance [1]. Due to their lack of technological expertise, the linked administration department finds it difficult to use these technologies. A pavement management system (PMC), which combines IoT and big data, is created as a solution to the issue. The PMS offers an entire management framework for road maintenance. The PMS, which is divided into three areas called Pavement identification and 3D modeling, Data analysis, and Decision Support, provides linked administrative departments and businesses with an automated and intelligent solution.

As per the viewpoint of [19], the first step in implementing the Road Management System is to evaluate the present state of the data, procedures, training, and IT requirements. The Road Database is first created before the Road Management System is put into place. The process of collecting data begins with a focus on traffic and road conditions. Processes for asset management are put in place for the yearly maintenance cycle [20]. Information on the road inventory, condition, expenses, and traffic is needed to plan and optimize the maintenance to attain this ideal state. A Road Management System designed to manage these responsibilities substantially simplifies the procedures of data gathering, storing, and processing. Realistic maintenance plans great increase in the reliability of cash allocation for maintenance.

Road maintenance preparation is a mathematical perfect issue, whereby the agent's preferences, data, limitations, and assumptions should all be considered. These factors are found in actual maintenance operations [10]. In maintenance preparation, when future maintenance treatments are prioritized and chosen within a limited budget, road user costs are anticipated. Future fuel prices, road conditions, vehicle performance, and unit costs of road users' costs are the primary elements influencing future unit road user costs.

3. Research Methodology

3.1. Research Philosophy and Approach

The current study applies the interpretivism research philosophy. This is because it works with small samples related to in-depth investigations having a qualitative form of data. This method is socially constructed which has the nature of interaction and participation in the findings of the research. It supports analyzing the qualitative data to confront the problems identified [21][22]. The current study applies the inductive research approach. This is because the study uses qualitative data in which data collection is used to explore a particular phenomenon. It deals with the identification of the themes and also the creation of the conceptual framework so that patterns can be determined for results and findings [23].

Accordingly, issues related to pavement management were discovered using the interpretivism philosophy which helps to draw out qualitative solutions in the current research. Moreover, relevant outcomes can also be generated. In addition, an inductive approach is used to find out the relationship among the variables like pavement management and predictive maintenance so that models used for the road's planning can be determined accurately. It will help in finding out the suitability of the road's planning and its management tactics using predictive maintenance techniques.

3.2. Research Choice and Strategy

The current study applies the mono-method research choice. This is because only one type of data is used throughout the investigation which has a qualitative nature. It is a type of data that is non-numeric and is completely based on theories and qualitative content. The mono method helps in maintaining simplicity to the reader to understand and relate the topic with the issues and solutions. It also supports avoiding any type of complications as well [24]. The current study applies the case study research strategy. This is because it contains empirical models and articles which contain real-life situations. It helps in analyzing the theories related to the research topic and then interpreting them for an appropriate discussion and findings. This is done to resolve the issues identified in the case study [22].

In the context of the current research aim and objectives, qualitative data has been used by referencing various articles based on pavement management and predictive maintenance. Qualitative data is used to find out the relationship and challenges along with the strategies in the road planning. A case study strategy is used to find out the concept and types along with the use of models and also the challenges or strategies of pavement management for advancing the road's planning using predictive maintenance.

3.3. Research Data Collection and Analysis

The current study applies secondary research data collection. This is because the current research is conducted in a limited time and cost. Therefore, this type of data collection saves time and cost along with the effort. It provides cleaned and structured data that have control over the collection process. It is collected indirectly because it is second-hand data that is already relevant following the research topic [25]. The current study applies thematic research data analysis. This is because it is considered one of the most common types of analyzing qualitative content. It mainly makes emphases identification and analysis along with interpreting the patterns of the qualitative data [26].

In the context of the current research aim and objectives, secondary data collection is used so that time can be saved because primary data collected is usually the unstructured data that is required to be cleaned which takes up the cost and effort as well. This is the reason why the data is collected by reviewing the already published articles and journals related to predictive maintenance and pavement management. In addition, thematic data analysis is used to first formulate the themes concerning the aim and objectives of the research. It means that there are five objectives so there will be five themes so that it can be analyzed and interpreted to find out the research outcomes and results accordingly.

3.4. Research Ethics

Several ethical considerations must be followed in the research and that is why the current study has considered various ethics while conducting the investigation. Some of the most important ethics are the maintenance of confidentiality of the data collected so that the final data can only be used in the current study and future work, and must be destroyed on a timely basis [27]. Moreover, there is no harm done to anyone either animals or plants or human beings. Results are communicated and represented accurately so that plagiarism and research misconduct can be avoided.

3.5. Research Gaps and Limitations

The previous research was conducted having the gaps that they were only based on the pavement management and the road's planning techniques and models. However, they were only limited to the quantitative data where facts and figures are used to interpret the results. Hence the current research is focusing on predictive maintenance along with pavement management and road planning. It is also focusing on qualitative data so that the theories and case studies can be analyzed. Moreover, the current study is only limited to secondary data in which only the already collected information is used in the current study. This has limited the usage of appropriate data following pavement management and predictive maintenance. Primary data helps in gathering the information as per the needs and requirements of the researcher so that findings can be more relevant.

4. Results and Findings

4.1. Theme 1: Concept and Types of Pavement Management Used in the Road's Planning

The concept of pavement management is based on the planning process which mainly includes the planning of repair and maintenance of the roadways networks. It also includes the planning of the paved facilities for better optimization of the condition of the pavement across the network as a whole. Moreover, it is used in airport runways and applied in ocean freight terminals [28]. Interestingly, three types of pavement management are used in road planning. Pavement condition analysis is the first type which is a project-level approach. In this type, each project is assigned based on the priority and number of factors which include location and safety. Priority assessment models are the second type which is also a project-level approach. In this type, it improves the pavement condition analysis which considers the future predicted conditions; based on the network-level decisions. Network optimization models are the third which is a network-level approach. It begins with the highest decision level and then it further progresses with the lowest decision level. It also determines the network management strategy in an optimum way.

4.2. Theme 2: Use of Predictive Maintenance for Advancing the Road's Planning

Predictive maintenance is very useful in advancing the planning of the road. This is because it is a type of technology that uses the tools and methods of data analysis to detect any type of anomalies in the operations. It identifies also every possible defect in the equipment to process and fix the equipment and the result without any failure. This is a strategy that is used to maintain the downtime tracking software in an advanced manner. In the context of road planning, several types of machinery are used to upgrade and repair the road and therefore, predictive maintenance keeps an eye on such equipment to update frequently so that it can work effectively in pavement management [29]. Pavement management highly requires predictive maintenance as different types of machinery are the important part and must work in a good flow for efficient and potential planning of the roads.

4.3. Theme 3: Models of Pavement Management for Evolving the Road's Planning with the Help of Predictive Maintenance

There are three empirical models of pavement management which help in evolving the road's planning using predictive maintenance. The deterministic pavement deterioration model is one of the models, and one of the most common models used because of its relative simplicity. It is easy to use and has a familiar nature as well. This method that makes use of the straight line extrapolation and also the S-shaped curve along with the polynomial constraints least squares and logistics growth models as well. The probabilistic pavement deterioration model is also one of the models [30]. Markov model is however one of the types of this model that is mostly used by organizations on the current basis. It has the process for developing the decision support system to manage pavement maintenance. Formulation of the distress indices is also the type of model, having a scale that ranges from 0 to 100. In this, 100 demonstrates the flawless pavement and having no distress whereas 0 demonstrates the worst situation. It calculates the transverse and longitudinal along with the fatigue cracking indices for each of the roadway segments.

4.4. Theme 4: Challenges Regarding Developing the Road's Planning Related to Pavement Management and Predictive Maintenance

Several challenges are faced at the time of road planning while using the tactics of pavement management with the help of predictive maintenance. Such challenges are the execution process which requires high technical skills in using the equipment that needs experts to execute. If there is no experience in executing then, it becomes a challenge for road planning [31].

Moreover, security and safety at the site are major concerns. Over-maintenance is also a problem as it takes extra time and cost in the entire process of planning. Sudden asset breakdown is considered the major challenge because technical equipment is majorly concerned with the technical glitches that result in hampering the whole process of predictive maintenance. Furthermore, data can be misinterpreted which can lead to more costs in terms of the transmission cost and its analysis. Another most affecting challenge is that the software of predictive maintenance does not consider the contextual information, for example, age of the equipment or any weather [32]. This can negatively impact the entire planning of road management and also the predictive maintenance of the operations.

4.5. Theme 5: Strategies for Overcoming the Challenges Associated with Pavement Management for Progressing the Road's Planning Using Predictive Maintenance

Some strategies must be undertaken at the time of road planning while using the tactics of pavement management with the help of predictive maintenance. Such strategies are the analysis of the historical data and also identifying the critical assets [33]. This helps in the accurate prediction by reviewing past data so that previous experiences can help in future predictions in terms of the equipment working and its related upgrades. Installing the internet of things sensors helps in safety and security along with the quick analysis of the prediction on a current and future basis. It is highly necessary to establish the parameters to use the equipment so that it can work for long term with less requirement of maintenance. Notably, it is vital to maintain the setting up of the action items during the triggers of the alert. Moreover, it must be noted that proper systems must be in the right place with the right people managing them [11].

5. Conclusions

Conclusively, pavement management is one of the most important concepts that is considered at the time of road planning and predictive maintenance. The findings of the current research were such that three types of pavement management were used in road planning including pavement condition analysis and priority assessment models with network optimization models. Three models were discussed as deterministic pavement deterioration model, probabilistic pavement deterioration model and the formulation of the distress indices. The study collected the data via a secondary research method and performed thematic analysis in order to find out the results of the entire study which thus brought about the aforementioned aim and objectives. In addition, several uses of pavement managements which include detecting any type of anomalies in the operations and identifying every possible defect in the equipment along with maintaining downtime tracking software and upgrading and repairing the road were noted.

The current study was conducted using the interpretivism research philosophy and inductive research approach. Challenges that were discussed include the execution process, security and safety along with the over-maintenance and transmission cost. Discussed strategies are the analysis of the historical data and identifying the critical assets along with installing the internet of things sensors and establishing the parameters for the use the equipment. The current study is however highly significant as it provides an in-depth information and analysis of pavement management and predictive maintenance in road planning. Construction companies for instance would benefit as it will help their industries to prevent issues in road maintenance, and to keep their construction practices in a good condition as well as reconstructing the road results in long-term cost and time. This study will play a vital role to avoid road planning and maintenance problems by maintaining a better system

performance

Nonetheless, future research is encouraged by researchers and should be based on the primary data which information was collected directly. Primary data helps in gathering the information as per the needs and requirements of the researcher so that findings can be more relevant. In addition, quantitative data could be used for numeric and factual type of information while tools and techniques could be investigated regarding pavement management and predictive maintenance for advancing the road's planning.

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