The Conceptual of Pavement Management System Based on IoT, Big Data, and Data Mining in Indonesia

Thomas Setiabudi Aden1, Hera Widyastuti1,*, Anak Agung Gde Kartika1

1Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia

Abstract. The country's economic development and people's lives require reliable transportation and logistics services. Therefore, road maintenance policies and techniques must be more comprehensive to ensure transportation infrastructure operations' efficiency. The inefficiency of road maintenance, among others, is due to the failure to identify and predict the level of damage that can cause fundamental data anomalies. Therefore, the current scientific development of road maintenance must be able to take advantage of the convenience of technology. Widespread technology implementation on the Internet of Think (IoT), big data, and data mining (DM) can be a solution to developing a better pavement management system. However, implementing these technologies is challenging due to the weak conception and availability of currently available resources. This paper offers a pavement system management implementation concept that can be developed in Indonesia to improve the existing system. The study results show that IoT, big data, and DM are believed to support a more intelligent and comprehensive pavement management system. The concept offered consists of three main things: identification of damage and 3D pavement modeling, data analysis, decision support systems, and collaboration of intelligent solutions in implementing maintenance in the field. This paper is equipped with an illustration of the concept of road maintenance based on IoT, big data, and DM, which can be implemented intelligently and simply in Indonesia.

1 Introduction

In the development of modern infrastructure systems, the availability of roads is an essential component. This matter is vital to sustainable and effective development [1]. In the last decade, infrastructure modernization has been speedy and massive in various parts of the world. This step is taken by increasing the integration of road infrastructure, which supports transportation needs in line with the speed of development. However, after building road infrastructure on a large scale, managing damaged roads is challenging for the organizers [2]. The low efficiency of pavement maintenance reduces the serviceability of the transportation system. This condition can result in inconvenience to travel activities and waste of resources. In addition, various road damages can lead to traffic accidents. Naturally, sustainable development will undoubtedly be limited in the long term due to budget constraints and priority shifts [3]. This condition can encourage road infrastructure service providers in each country to seek the latest problem-solving approaches.

In Indonesia, substantial funds are invested in road maintenance every year. According to data from the Directorate General of Highways (DGH), the cost of maintaining roads and bridges continues to increase [4]. The preservation budget in the last three years is more than 20 billion annually or 40% of DGH's budget. If the limited availability of funds is not utilized correctly, it can cause an even heavier fiscal burden. Therefore, evaluating road conditions is vital to allocate limited resources [5]. Traditionally, the implementation of such evaluations has relied heavily on manual visual inspections.

However, the large number of roads and the complexity of the road network can make evaluating road conditions a problematic task. In addition, the evaluation of road conditions is usually based on the skill and experience of the inspector, which varies from person to person. Lack of human resources and inaccuracy of work can result in decreased performance in evaluating road conditions. Thus, these conditions can cause the policymakers to be more optimal in making decisions. Accepted risk, some damaged roads cannot be treated on time, which can accelerate road damage [6].

Along with the changing times, in this era of digitalization, the discrepancy between the maintenance of low-efficiency transportation infrastructure and the need for an ever-increasing number of vehicles must be immediately found a solution. Information technology can support the sustainable management of civil infrastructure systems. The right policy can be developed based on sufficient data and the proper interpretations [7]. Maintenance of roads and bridges is a technical and administrative activity to maintain the condition of infrastructure at an acceptable level. Disruptive technological developments and the digital revolution in...
various fields have prompted the parties to act immediately. This condition also occurs in the construction and maintenance of infrastructure.

Emerging disruptive technologies such as big data, the Internet of Things (IoT), and Artificial Intelligence (AI) should be able to strengthen the infrastructure systems [8]. As an essential part of the infrastructure system, road maintenance has attracted the attention of various parties in recent years. Some researchers have innovatively proposed approaches to identify road damage from images and visualize pavement conditions. The concept offered is an AI-based method that detects pavement conditions. The idea is expected to replace manual inspection activities. Technology-based automation can significantly increase the Pavement Management System's (PMS) efficiency. Some studies have shown the effectiveness of IoT and big data technologies’ effectiveness in road and bridge preservation [9].

Only now, the digital transformation process for modern road maintenance has a systematic workflow [10]. The concept of a pavement management system that contains data acquisition, data analysis, and decision support still needs to be fully implemented. Indeed, many studies focus on this problem and believe that it can increase the efficiency of road and bridge maintenance to a certain level. However, until now, there is still a gap between research and actual implementation. The main problem is that no concept connects AI and IoT techniques to PMS that are adjusted to the authorities’ policies, as we know that PMS consists of various functional modules that require operational efficiency between different modules.

This paper aims to develop solutions for road maintenance policyholders and assist parties in overcoming existing challenges by utilizing IoT and big data. Hopefully, this writing can reduce the gaps in the previous studies. This paper will describe the PMS concept, which, in an integrated manner, is expected to improve the road maintenance system from the traditional mode of operation to an intelligent and automatic method adjusted to policies in Indonesia. Combining the techniques and facilities available in the conventional operation process makes it more concise for the related administrative and field management levels. In addition, from the perspective of the efficiency of road infrastructure management, this pavement management system opens itself up to developing other digital infrastructure systems to realize a more comprehensive collaborative improvement of infrastructure management.

2 Concept of Pavement Management System

PMS is a system that identifies optimal strategies at various levels of pavement maintenance management with adequate performance. This system includes but is not limited to maintenance procedures and scheduling of rehabilitation activities based on performance. This system consists of various things that complement each other and continue developing a road pavement management pattern, from planning, construction, and operation to continuous maintenance [11].

Road pavement is a layer between the vehicle traffic load and the subgrade, which is more constructive so that the subgrade can support the load. Therefore, pavements must be appropriately managed and precisely in terms of conceptual approaches, application of technology (tools, materials, work methods), efficient funding, and research to obtain better maintenance models. Currently, funding for maintenance is getting tighter, and budget restrictions occur in various countries [12]. Meanwhile, traffic growth and transportation needs are increasing and growing over time. These conditions require extraordinary measures for better PMS implementation to maintain road performance using the available budget.

2.1 Pavement Management System Smart Approach

Through the support of IoT, big data, and AI, digitization has gone global in realizing future data automation with intelligent systems. Based on this, PMS must change from a traditional pattern to a more modern one that contains intelligence. To build an efficient PMS, not only functional requirements must be considered, but smartness is also very important. Smartness is the automatic coordination between one system and another, such as the Building Information Modeling (BIM) system. The basic functional modules can be described and grouped to develop a modern PMS using the following approaches.

2.1.1 Survey Automation

The availability of data and information on overall road conditions is an integral part of a reliable road maintenance system. The data relies heavily on periodic pavement checks. Traditionally, manual inspection was the primary way to investigate road conditions. It is always insufficient and results in low resource allocation efficiency. A more comprehensive view of road conditions is needed to overcome this situation. However, the limited workforce cannot be forced to carry heavier and more intensive workloads. The development of IoT technology offers the possibility to solve this problem. Based on various products in sensor technology, such as industrial cameras, infrared cameras, and ground-penetrating radar, IoT technology can realize interactions between items. Road sensors are also currently developing quite rapidly. Once integrated and installed in the vehicle, the equipment can automatically measure and upload road surface parameters while running. For the Pavement Management System, data collection is an introductory module that supports the following modules. Real-time road condition data can be collected dynamically and transferred to relevant sectors for further analysis by laying out a comprehensive IoT-based sensing and information-gathering infrastructure. Indonesia integrates technology into the Hawkeye car [13].
2.1.2 Data Perspective

Over time, the availability of road condition data continues to grow and increase exponentially. Meanwhile, raw data cannot be directly used to support decision-makers. In the process, extracting information hidden in a large amount of data is necessary to interpret the data correctly. The rapid development of data processing tools has brought new insights and opportunities. The challenges of processing data using various current approaches are part of a different perspective. Data mining can simplify processing data by finding the correct interpretation [14]. Figure 1 shows the practical data mining process approach, which starts with a perspective understanding of the data.

![Data Perspective](image)

Fig. 1. Data Perspective of Road Preservation

Normative analysis helps research solutions appropriate to a particular situation's conditions, which will help managers respond accurately to different circumstances. Spatial analysis helps analyze location-based data and interpret spatial relationships between physical objects. Streaming analytics, also called dynamic analytics, helps analyze large amounts of “dynamic” data sets. In other words, the real-time data stream will be analyzed to detect abnormal events. This approach is likely the answer for anomalous data. Time series analysis is based on a time series data approach, and time series analysis is constructive for knowing trends and rules that occur in road disturbances and damage. The last is integration analysis; through big data collection, data mining can be carried out using the help of IoT.

In conclusion, data analysis can help managers make judgments and take appropriate actions. This process is a supporting process of the pavement management system. Advanced analytical methods of big data are developing speedily [15]. Integrating data mining and big data with IoT tools can help managers gain insight from a comprehensive perspective and support better decision-making.

2.2 Integration System

With the three modules mentioned above, an automated data-based system should be realized better. Apart from road infrastructure, the digital revolution has also materialized in other supporting components, including but not limited to the Intelligent Traffic System (ITS) and the Building Infrastructure System (BIM). Interaction and integration with other infrastructure systems are also crucial for improving road infrastructure systems. The essential function of this pavement management system is to support the management of the overall infrastructure without overlapping the entire system. Adequate coordination of the system will improve the performance of infrastructure as the whole system. At an advanced level, integrating these systems will rapidly promote establishing a smart city or intelligent design, which is the future development trend.

Intelligent systems are implemented by imitating natural processes, such as the brain and natural selection [15]. In addition, soft computing techniques allow data processing to reduce uncertainty, imprecision, and ambiguity. In the mid-early 1960s, a new branch of computer science began to attract the attention of most scientists. This new branch, AI, can be defined as the study of making computers work better for people. To achieve this goal, the AI was developed by imitating human behavior.

2.3 Modern-Integration Concept

Discussions on IoT, data mining, and other advanced technologies have been extensively reviewed and explored in various industries by experts. Although not mature enough, this technology continues to grow all the time. This combination of technologies will transform traditional industrial patterns into entirely new approaches. This approach will significantly change lives and cultures. Implementation of new technologies in road infrastructure can improve efficiency and improve PMS intelligence at the same time. Experts have explored various approaches to improve road maintenance performance from different perspectives. The success rate will be optimal if the methods from other departments are integrated into one reliable and intelligent management system.

![Modern PMS Integration Concept](image)

Fig. 2. Modern PMS Integration Concept

Overall, upgrading the road maintenance system aims to standardize the process of intelligent maintenance
operations. In addition, it is expected to realize an integrated PMS and increase a better level of performance. Furthermore, the system compiled must produce progress from an overall perspective. This modern-integration concept is developing an existing system by dividing it into four main sub-systems. 1) Smart-Inspection, 2) Smart-Solution, 3) Smart-Automation Tools, and 4) Smart-Emergency Response and other functions. A complete picture of the four sub-systems can be seen in Figure 2. In addition, to meet future trends, it is necessary to increase the scientific analysis of road conditions and establish a road condition monitoring mechanism based on the latest technology.

Thus, a Pavement Management System (PMS) framework can be developed to eliminate existing gaps and offer solutions to policyholders and implementers. Pavement maintenance is finding damage early, repairing damage, and maintaining the normal condition of road infrastructure so that the level of service is maintained. The development of the information technology industry is speedy, and data collection knowledge is increasing. An exemplary extensive database can take advantage of computer technology with various primary and supporting applications. All data collected and stored in a suitable database can become precious knowledge (e.g., trend models, behavior models) used to support decision-making and optimize action.

The PMS aims to use limited funds and other resources better and make informed decisions according to the requirements of relevant laws and regulations regarding road maintenance and the actual situation of a particular road. Through the approaches above, the theory of road maintenance sub-systems combined with IoT, big data, and data mining, it can be defined that road maintenance management includes three subsections: 3D detection and modeling of pavement layers, data analysis, and preparation of decision support concepts. In Figure 3, it can be seen in full the relationship between the subsections and the entire workflow.

One of the steps in developing a road performance prediction model in a pavement management system is processing road condition data in a KDD process to form poverty data mining. DM is a logical combination of data knowledge and statistical analysis developed in business knowledge or a process that uses statistical, mathematical, artificial intelligence, and machine-learning techniques to extract and identify valuable information for knowledge related to various large databases. In the KDD stage, the DM algorithm is equipped with the dataset used during the learning phase to be developed into a data-driven model [16]. The model can be described as a relationship between input and output, which can provide helpful information as an implementation of the concept of this framework can be seen in section 3.

3 Implementation of Smart Pavement Management System

3.1 3D Survey Module

The module developed to detect road pavement conditions is the basis and beginning of the entire process. Existing technology can help policymakers and implementers improve low labor efficiency. Various sensors, including 3D-based pavement data information
equipment, are needed to meet data collection needs. Also, super HD cameras and other necessary equipment such as encoders and GPS. These various components are integrated into the detection vehicle. Manual inspection will be replaced by detection vehicles. With regular patrols, multidimensional data can be collected dynamically and automatically. The survey vehicles currently owned by DGH can be enhanced with hardware enhancements and other necessary features.

The data collected includes raw road condition data, GPS data, and other parameter data. This data can be displayed in an intuitive form through visualization. Based on 3D point cloud laser technology, which has been used in various fields of civil engineering in recent years. The developed 3D model of road conditions is expected to help achieve real-time monitoring with a dynamic visual display of road conditions [17]. The module is structured to integrate 3D visual information from all roads through the developed visualization platform. The collected data is then processed and embedded into the venue. As a result, decision-makers are expected to find it easier to access detailed road information such as location, inspection records, and other relevant parameters.

3.2 Data Analysis

3.2.1 Automation of Deterioration Classification

After the road damage information is extracted from the 3D model, the available data will be processed using an image recognition algorithm. Road damage will be classified automatically to support the development of solutions in the following process. For example, the damage can be classified into various types, such as cracks, potholes, and depressions. Classification standards can be adapted to the damage standards used in Indonesia. In addition to classification, the level of road damage will also be evaluated, for example, the depth of the ruts. After this step, detailed information on all road disturbances is collected for further analysis.

3.2.2 Road Condition Evaluation

The module of road condition evaluation that is prepared must be able to shorten decision-making. Therefore, pavement evaluation must be carried out regularly to determine pavement performance at a certain point and in the future. This pavement evaluation will record characteristics that can describe pavement performance through several indices. Several road condition assessment criteria are used in Indonesia's pavement management system. Surface Distress Index (SDI), International Roughness Index (IRI), and Pavement Condition Index (PCI) are used to evaluate the quality of road services comprehensively.

This evaluation will determine the ability of road pavement to fulfill the three essential functions of road pavement (comfort, safety, and service efficiency). Meanwhile, pavement evaluation can be classified into structural and functional assessment based on the characteristics surveyed. The first is a practical evaluation, which is an evaluation in the form of information about the aspects of the road pavement that directly affect the safety and comfort of road users and road services. The main elements surveyed are skid resistance, surface texture, road roughness, and serviceability. The second is a structural evaluation, which is an evaluation in the form of information about the performance of the pavement structure against traffic loads and environmental conditions. In this case, a characteristic survey will also assist in obtaining information about the performance of the pavement structure, pavement damage, and the mechanical and structural properties of the road. In addition, pavement damage will indirectly affect functional road problems such as pavement bleeding, skid resistance, and cracks in road joints, affecting road roughness.

3.2.3 Need Analysis of Pavement Maintenance

Indonesia has an extensive road network area with various types of problems. This condition by itself requires multiple and complex kinds of maintenance. Therefore, in its implementation, it is necessary to prioritize. Based on different road conditions and a certain level of difficulty, decision-makers must be able to determine which maintenance needs are more urgent according to standard evaluation standards. Thus, damaged roads with a higher priority level will be treated more promptly. In addition, it can minimize inconvenience for vehicles and pedestrians. If these steps are followed, the performance of the road infrastructure system will improve even better.

3.2.4 Data Based on Road Conditions

Over time, the data collected from complex road networks grew exponentially. The collected data is significant for deeper analysis. For example, analysis of time series data on road maintenance needs will be helpful for feedback and improvement of the road network system. To integrate this essential data, building a road condition database is irreversible. After data collection and analysis, specific road conditions become explicit, and managers can make decisions according to a condition-based maintenance strategy, which emphasizes a combination of data-driven reliability models and collected sensor data. Condition-based maintenance applications support decision-making with data collection and condition monitoring. Information from the detection of road conditions can be used to calibrate the need for specific maintenance activities and help schedule maintenance activities.

3.3 Life-Cycle Costing Analysis

Defining a policy by selecting the lowest initial cost cannot guarantee an economic advantage over other options. Low initial costs without considering the consequences that will occur during the life of the road plan usually cause the required routine and periodic
maintenance costs to be greater than choosing a higher initial cost. Life-Cycle Costing Analysis (LCCA) is a reasonably comprehensive economic evaluation method. LCCA seeks to optimize costs and maximize operational assets over their useful life by identifying and calculating all sufficiently significant costs using the Net Present Value (NPV) technique [18]. Furthermore, several definitions of life-cycle costing used today are practical compared to other existing methods [19]. Life-cycle costing is the conception and development through operation until the end of its useful life. Make the life-cycle costing procedure more structured and easily understood through a systematic flow base like Figure 4. LCCA is very often used to carry out calculations and government investment decisions.

Fig. 4. The procedure of life-cycle costing

All costs associated with alternative pavement management incurred by the operator during the analysis period can be expressed in monetary terms. This condition includes initial construction costs, subsequent rehabilitation and construction costs, maintenance costs, traffic control costs during construction, maintenance, and rehabilitation, and demolition or write-off costs or the residual value of the pavement structure at the end of the analysis period [20]. Only the costs incurred by the operator that differ significantly from the alternatives must be included in the LCCA. For example, engineering and construction management expenses can be excluded if they are the same for all other options.

3.4 Decision Support Model

3.2.1 Collaboration System

In the last decade, the development of various infrastructures has been growing. However, different infrastructure functional systems such as transportation, energy, trade, communication, and infrastructure have shown strong development trends. The simple superposition of these systems has led to a series of urban and environmental problems, for example, repeated investment. In the long run, inadequate cooperation between urban systems stifles a city’s "smartness." In addition, the collaboration of different administrative institutions is a win-win situation. One specific example is data sharing, where all parties benefit from having access to a broader spatial layout. Mastering regional density data and dynamic traffic flow for road infrastructure stakeholders will help support more scientific decision-making.

Based on the prevailing PMS conditions, information from other systems is combined with the road conditions database, forming an information integration platform. Policyholders will consider input from other related systems in the decision-making process. Also, additional outside information may be required, so the information integration platform is open to potentially helpful information.

3.4.2 Prediction, Solution, and Feedback

The proposed Integration Platform offers the necessary information for decision-makers, which can be continuously enriched. Then, managers can develop road maintenance solutions based on this information. Furthermore, after decision-making, tracking and feedback will help find system deficiencies and improve system performance continuously in the future. Moreover, managers can discover road damage development trends by utilizing the abundant data and choosing the appropriate data-based method. Therefore, this concept will support decision-making in the next period.

In this stage, data mining tasks are arranged based on their ability to solve various problems with interpretation and other statistical operations on the data [21]. Depending on the type of pattern found, data mining tasks are usually classified into two categories: predictive and descriptive. The predictive approach performs inferences on the data to predict the output variables’ unknown values, considering the input variables’ known values [22]. Meanwhile, the descriptive approach is to characterize and summarize the various general characteristics of the data to increase understanding and provide broad information. Data mining tasks depend on the user’s ability to identify a problem early and its purpose.

Finally, the Smart-PMS developed above has several advantages compared to traditional management systems. First, the concept of this system is believed to be able to detect road damage automatically with high precision. Second, it can quantify the types and types of damage based on 3D. Third, continuously extract information on road damage using intelligent algorithms that are constantly being refined. Fourth, it can synchronize and collaborate with other systems that have been developed. Fifth, it offers a standard system regarding the trend of damage development and the required road maintenance.

4 Conclusion

Road infrastructure is one of the primary keys to the availability of national transportation and logistics services. The ever-increasing traffic mileage and the increasing need for transportation capacity pose challenges for better road infrastructure management and maintenance. In the concept of sustainability, PMS must start implementing innovative technology and focusing on digitizing infrastructure, network, intelligence, and integrated development of equipment and facilities.
Through the IoT, big data, and data mining approaches, the system will continue to be driven in the transformation process of transportation modernization. Collecting series data neatly and automating precise data interpretation based on artificial intelligence can ensure the reliability of modern pavement management systems.

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